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THE NEW GRAVITY SYSTEM: CHANGES IN INTERNATIONAL GRAVITY BASE VALUES AND ANOMALY VALUES

GEORGE P. WOOLLARD and VALERIE M. GODLEY

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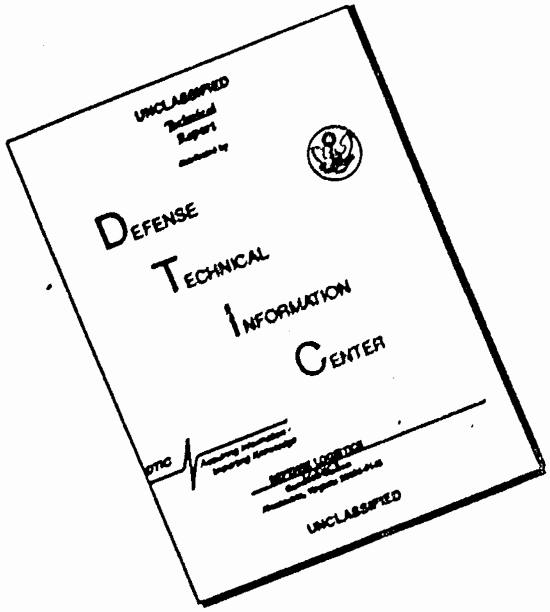

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The effect of the adoption of the Geodetic Reference System 1967 (GRS 67) theoretical gravity formula and the International Gravity Standardization Net 1971 (IGSN 71) on gravity anomaly values is assessed. The gravity standard represented in the IGSN 71 values is shown to not conform to that of modern absolute gravity values as well as one might expect although on an overall basis the apparent discrepancy does not appear to be greater than about 0.03 mgal per 1000 mgal change. That the source of error probably lies in the IGSN 71 adjustment is brought out by the close agreement (0.03 mgal) for pendulum and absolute gravity intervals between Washington and Teddington and Paris and Teddington which differ by approximately 0.1 mgal from the IGSN 71 intervals between these sites. The Potsdam datum correction of -14.0 mgal incorporated in the IGSN 71 values is shown to be essentially correct to within 0.03 mgal. An evaluation of 773 international gravity values published by Woollard and Rose (1963), which have been used extensively for gravity control, using the IGSN 71 values as a standard shows the following: (A) there is no detectable difference in gravity standard defined for observations at pendulum sites except in South America and India; (B) the median average datum difference relative to the IGSN 71 values is +14.7 mgal; (C) On an areal basis the gravity standard difference defined in South America, which amounts to 0.2 mgal per 1000 mgal, does characterize the Woollard and Rose values in other areas but is masked by compensating tares (datum shifts) when only the data for pendulum sites is considered. A correction table is given which permits anomaly values based on the old (1930) International Gravity Formula and Woollard and Rose (1963) gravity base values with an average datum offset of 14.7 mgal (or other datum) to be converted directly to the new gravity system. The latter is particularly applicable to the conversion of gravity anomaly maps for which the original data have been lost.

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INTRODUCTION

There were two actions taken by the International Association of Geodesy at the 1971 Moscow meeting of the International Union of Geodesy and Geophysics which have worldwide significance in the use of gravity for geodetic, geological and geophysical investigations. One was the adoption of a new geodetic reference system which resulted in a significant modification of the International Gravity Formula that had been in use since 1930 for defining the theoretical sea level value of gravity. The other, having two related parts, was the adoption of a new value for the Potsdam international gravity datum and an international gravity standard based in large measure on ten modern absolute gravity determinations. In combination, these actions made all former gravity anomaly values obsolete and incompatible in varying amounts, depending primarily on latitude and to a lesser degree on gravitational attraction, with anomaly values computed under the old (1930) reference system, the old Potsdam datum value and the various gravity standards that had been in use.

The purpose of this paper is fourfold: (1) to present the change in theoretical gravity values occasioned by the adoption of the new reference ellipsoid (Geodetic Reference System, 1967), which will be referred to as GRS 67; (2) to evaluate the reliability of the gravity standard and Potsdam datum correction incorporated in the values of the International Gravity Standardization Net (IGSN 71) prepared by Morelli et al. (1974) and now being adopted by most countries for gravity control and the calibration of gravimeters; (3) to establish the difference between the IGSN 71 values and those published by the Society of Exploration Geophysicists (Woollard and Rose, 1963) which have been used extensively for gravity control throughout the world; (4) to present a correction scheme that will permit gravity anomaly values based on the old International Gravity Formula and the Woollard and Rose (1963) or other base values to be converted to those that would be obtained using the new GRS 67 theoretical gravity formula and the IGSN 71 base values, without complete recomputation of anomaly values which in many instances would not be possible because of the loss of original field data.

Although Morelli (1976) has presented cogent arguments for the adoption of the GRS 67 theoretical gravity formula for computing anomaly values and for the use of the IGSN 71 gravity values for base station datum control and the calibration of high range gravimeters, his paper does not take up any of the points outlined above as objectives of this present paper.

THE GRS 67 THEORETICAL GRAVITY FORMULA

As the basis for the determination of the GRS 67 theoretical gravity formula is presented in detail in Geodetic Reference System Special Report 3 of the Association Internationale de Geodesie (1971), it will suffice here to mention only that the adoption of GRS 67 results in significant changes in the theoretical values of gravity at sea level. This is occasioned by a change in all of the constants in the old (1930) International Gravity Formula and in the sign of the second order latitude term as a consequence of the correction to the Potsdam datum, a change in the earth's equatorial radius, and a change in the degree of polar flattening (f) from f=1/297 to f=1/298.25.

These changes are best seen from a comparison of the old (1930) International Gravity Formula and that for GRS 67 as shown below.

1930 International Gravity Formula

$$g_o=978.049\ (1+0.0052884\sin^2\phi - 0.0000059\sin^2 2\phi)$$

1967 Geodetic Reference System Formula

$$g_o= 978.031846\ (1+0.005278895\sin^2\phi + 0.000023462\sin^4\phi)$$

In Table 1 the difference in theoretical sea level gravity values occasioned by the adoption of GRS 67 on theoretical sea level gravity values for each 1° change in latitude between the equator and the poles is presented, and in Figure 1 these changes are shown graphically as a function of latitude. As seen from an inspection of the data shown in Table 1 and also Figure 1, the differences in theoretical sea level values of gravity using the two equations is non-linear, and varies from -17.15 mgal at the equator to -3.57 mgal at the poles.

THE IGSN 71 GRAVITY STANDARD

The IGSN 71 gravity standard is based in large measure on ten modern absolute gravity determinations and in particular those made by Hammond and Faller (1971). These two investigators,using the laser-interferometer free fall gravity system developed by Faller (1963, 1965) and also described in Faller and Hammond (1970), made seven of the ten measurements adopted. Although the absolute gravity determinations made with the Faller and Hammond apparatus at Fairbanks, Alaska and Bogota, Columbia,which embrace a gravity interval of approximately 4,845 mgal, might be regarded as the key measurements in determining the IGSN 71 gravity standard, the standard, as will be shown, is heavily dependent

Table 1

Change in Theoretical Sea Level Gravity

1930 International Gravity Formula

1971 Geodetic Reference System 1967 Formula

	1930 ICF	1967 GRS	Diff (-)		1930 ICF	1967 GRS	Diff (-)
0°	978.04900	978.03185	.01715	22°	978.77206	.75681	.01525
1°	978.05057	.03342	.01715	23°	978.83569	.82061	.01508
2°	978.05527	.03813	.01714	24°	978.90151	.88660	.01491
3°	978.06310	.04599	.01711	25°	978.96943	.95471	.01472
4°	978.07406	.05697	.01709	26°	979.03939	979.02485	.01454
5°	978.08812	.07107	.01705	27°	979.11129	.09694	.01435
6°	978.10527	.08826	.01701	28°	979.18504	.17090	.01414
7°	978.12548	.10853	.01695	29°	979.26057	.24661	.01396
8°	978.14875	.13186	.01689	30°	979.33776	.32401	.01375
9°	978.17503	.15821	.01682	31°	979.41655	.40300	.01355
10°	978.20429	.18755	.01674	32°	979.49681	.48348	.01333
11°	978.23651	.21985	.01666	33°	979.57847	.56535	.01312
12°	978.27164	.25507	.01657	34°	979.66142	.64852	.01290
13°	978.30963	.29317	.01646	35°	979.74556	.73288	.01268
14°	978.35045	.33409	.01636	36°	979.83078	.81833	.01245
15°	978.39404	.37780	.01624	37°	979.91700	.90477	.01223
16°	978.44036	.42424	.01612	38°	980.00409	.99209	.01200
17°	978.48934	.47335	.01599	39°	980.09196	980.08019	.01177
18°	978.54093	.52507	.01586	40°	980.18049	.16896	.01153
19°	978.59506	.57935	.01571	41°	980.26959	.25829	.01130
20°	978.65167	.63611	.01556	42°	980.35913	.34807	.01106
21°	978.71069	.69529	.01540	43°	980.44902	.43820	.01082
22°	978.77206	.75681	.01525	44°	980.53915	.52856	.01059

Table 1 (cont)

Change in Theoretical Sea Level Gravity

1930 International Gravity Formula

1971 Geodetic Reference System 1967 Formula

	1930 IGF	1967 GRS	Diff (-)		1930 IGF	1967 GRS	Diff (-)
44°	980.53915	.52856	.01059	63°	982.15148	.14512	.00636
45°	980.62939	.61905	.01034	64°	982.22376	.21759	.00617
46°	980.71966	.70955	.01011	65°	982.29411	.28813	.00598
47°	980.80982	.79995	.00987	66°	982.36244	.35663	.00581
48°	980.89978	.89015	.00963	67°	982.42866	.42302	.00564
49°	980.98943	.98003	.00940	68°	982.49269	.48722	.00547
50°	981.07865	981.06948	.00917	69°	982.55445	.54914	.00531
51°	981.16733	.15840	.00893	70°	982.61387	.60872	.00515
52°	981.25537	.24667	.00870	71°	982.67088	.66587	.00501
53°	981.34267	.33419	.00848	72°	982.72540	.72053	.00487
54°	981.42910	.42086	.00824	73°	982.77736	.77263	.00473
55°	981.51458	.50656	.00802	74°	982.82671	.82211	.00460
56°	981.59899	.59118	.00781	75°	982.87338	.86890	.00448
57°	981.68222	.67464	.00758	76°	982.81731	.91295	.00436
58°	981.76419	.75682	.00737	77°	982.95846	.95420	.00426
59°	981.84478	.83762	.00716	78°	982.99676	.99260	.00416
60°	981.92390	.91695	.00695	79°	983.03218	983.02811	.00407
61°	982.00146	.99471	.00675	80°	983.06466	.06068	.00398
62°	982.07734	982.07079	.00655	81°	983.09417	.09027	.00390
63°	982.15148	.14512	.00636	82°	983.12068	.11684	.00384

Table 1 (cont)

Change in Theoretical Sea Level Gravity

1930 International Gravity Formula

1971 Geodetic Reference System 1967 Formula

	1930 IGF	1967 GRS	Diff (-)		1930 IGF	1967 GRS	Diff (-)
82°	983.12068	.11684	.00384	86°	983.19602	.19238	.00364
83°	983.14414	.14036	.00378	87°	983.20707	.20345	.00362
84°	983.16454	.16081	.00373	88°	983.21497	.21138	.00359
85°	983.18184	.17816	.00368	89°	983.21972	.21613	.00359
86°	983.19602	.19238	.00364	90°	983.22130	.21772	.00358

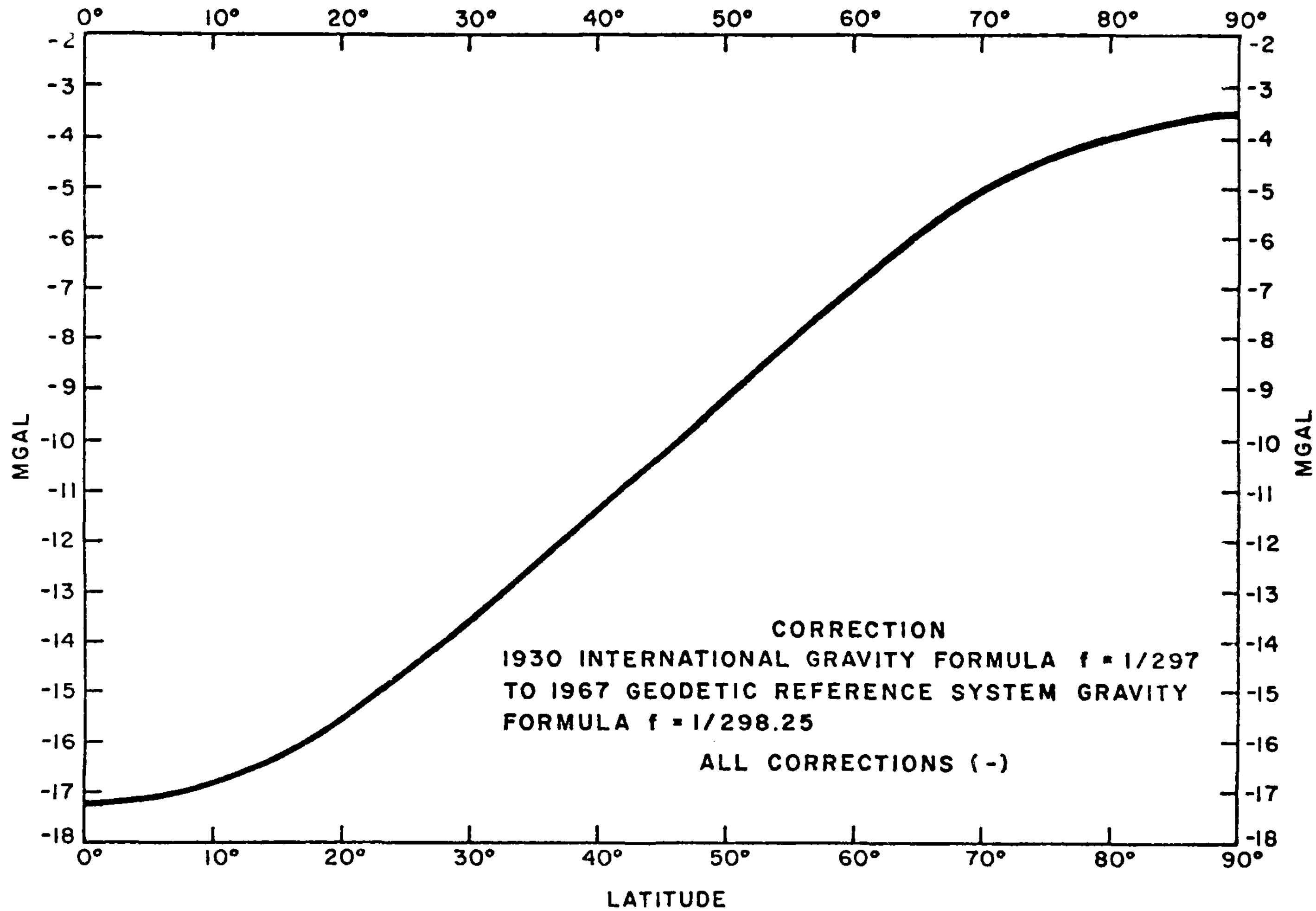


Fig. 1. Difference between Theoretical Sea level gravity values as determined by the 1930 International gravity formula and the Geodetic Reference System 1967 gravity formula.

on the other measurements by Hammond and Faller at Denver, Colorado, Middletown, Conn., Gaithersburg, Md., Bedford, Mass., Teddington, England and Sevres, France as well as the absolute determinations by Tate (1968) at Gaithersburg; Cook (1967) and Cook and Hammond (1969) at Teddington and Sakuma (1966, 1970 and 1971) at Sevres as well as some 1200 relative gravity pendulum measurements.

The apparent reliability of the Hammond and Faller measurements is of the order of ± 0.04 mgal as gauged from the standard deviations in values at each site and the base closure of 0.05mgal obtained after completing the field program. This degree of reliability is also indicated by the comparisons of their values with those obtained for the other modern absolute gravity determinations at Gaithersburg, Teddington and Sevres. Although there were problems associated with the Hammond and Faller observations at Bogota, the uncertainty in this measurement was not thought to exceed 0.09 mgal.

In Table 2 the absolute gravity values used in establishing the IGSN 71 gravity standard are listed along with the values that were adopted after applying the latitude dependent earth tide correction term of Honkasalo (1964) for each site. In Table 3 the IGSN 71 adjusted values of Morelli et al. (1974) for each of these sites are compared with the adopted absolute values of Table 2, and the site to site interval values also compared both sequentially and on an accumulative basis from Fairbanks, Alaska to Bogota, Colombia. The difference in absolute values and the IGSN 71 adjusted values brought out in Table 3, and shown graphically as a function of absolute gravity in Figure 2, is related to the

Table 2

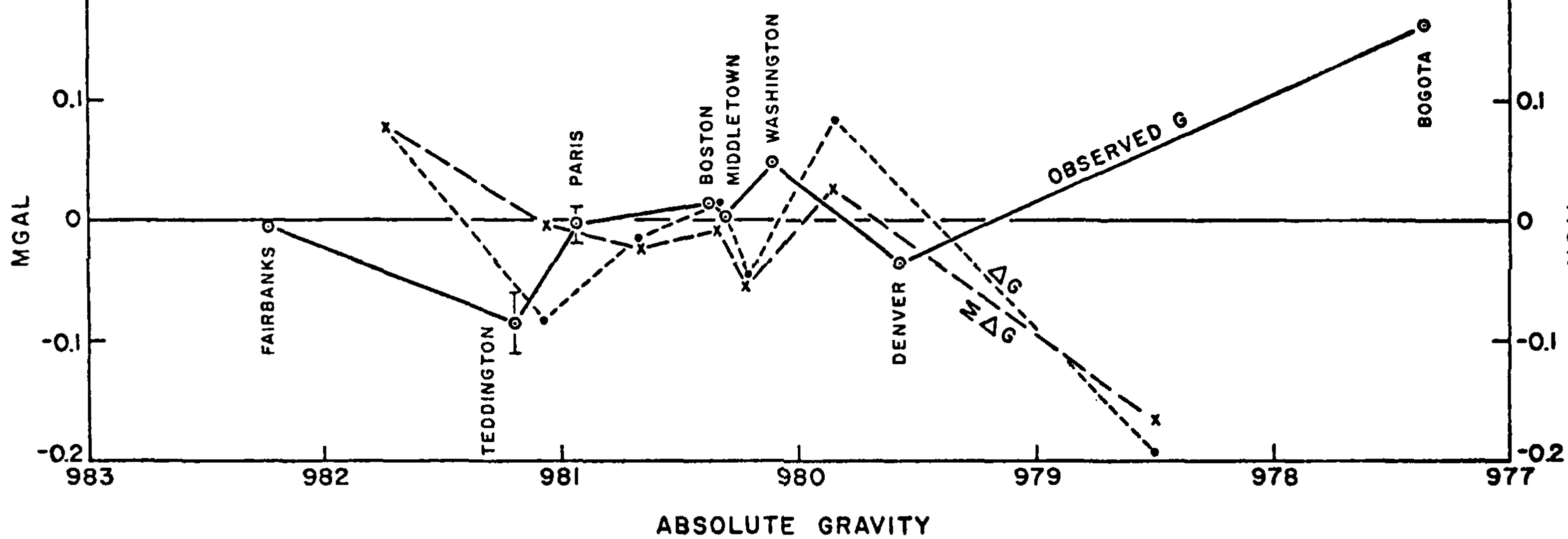
Observed and Adopted Absolute Gravity Values

	Observer	Year	Observed Value	Honkasalo Corr.	Adopted Value
Univ. Alaska	Hammond-	1971	982,234.933 ±0.042	+0.054	982,235.007
Natl. Phys. Lab. Teddington 'E'	Cook	1967	981,181.820 ±0.13	+0.031	Corrected to Site 'A' (Pendulum Base)
	Cook-Hammond	1969	181.88 ±0.13		981,181.84
	Hammond-Faller	1971	181.930 ±0.042		981,181.891
Int.Bur.Wts.Meas. Paris 'A'	Sakuma	1966	980,925.975 ±0.01	+0.026	
	Sakuma	1970	925.965 ±0.006		
	Sakuma	1971	925.931 ±0.005		980,925.957
	Hammond-Faller	1971	925.960 ±0.041		980,925.986
AFRCL, Bedford Boston 'A'	Hammond-Faller	1971	980,378.671 ±0.042	+0.014	980,378.685
Wesleyan Univ. Middletown 'A'	Hammond-Faller	1971	980,305.306 ±0.041	+0.012	980,305.318
N.B.S. Gaithersburg Washington 'V'	Tate	1968	980,101.8 ±0.3	+0.007	Corrected to site 'V'
Aux. Site 'I'	Hammond-Faller	1971	102.394 ±0.055		980,101.271
Univ. Denver Denver 'A'	Hammond-Faller	1971	979,597.708 ±0.042	+0.008	979,597.716
Univ. Nationale Bogota 'C'	Hammond-Faller	1971	977,390.015 ±0.087	-0.036	977,389.979

Table 3

Comparison of Adopted Absolute Values and IGSN 71 Values

Site		(1) Adopted Abs.Values	(2) $\Sigma\Delta g$ mgal	(3) IGSN 71	(4) $\Sigma\Delta g$ mgal	(1-3) mgal	(2-4) mgal
Univ. Alaska	(HF)	982,234.953 ±0.042		2,235.00		+0.047	
Site 'E'		Avg. (-1,053.087)	-1053.087	(-1053.22)	-1053.22		+0.133
N.P.L.	(HF)	981,181.891 ±0.50		1,181.78		-0.086	
Teddington 'A'	(C)	181.84 ±0.13					
	Avg.	981,181.866					
		Avg. (-255.894)	-1308.981	(-255.81)	-1309.03		+0.049
PIPM, Sevres	(HF)	980,925.986 ±0.041		0,925.97		-0.002	
Paris 'A'	(S)	925.957 ±0.03					
		980,925.972					
		Avg. (-547.287)	-1856.268	(-547.27)	-1856.30		+0.032
AFCRL, Bedford	(HF)	980,378.685 ±0.042		0,378.70		+0.015	
Boston 'A'		Avg. (-73.367)	-1929.635	(-73.38)	-1929.68		+0.045
Wesleyan Univ.	(HF)	980,305.318 ±0.041		0,305.32		+0.002	
Middletown 'A'		(-204.047)	-2133.682	(204.00)	-2133.68		-0.002
N.B.S., Gaithersburg	(T-HF)	980,101.271 ±0.055		0,101.32		+0.049	
		(-503.555)	-2637.237	(-503.64)	-2637.32		+0.083
Univ. Denver	(HF)	979,597.716 ±0.042		9,597.68		-0.036	
Denver 'A'		(-2,207.737)	-4844.974	(-2207.54)	-4844.86		-0.114
Univ. Nacional	(HF)	977,389.979 ±0.08		7,390.14		+0.161	
Bogota 'C'							



DIFFERENCE ISGN 71 VALUES AND ABSOLUTE G VALUES

Fig. 2. Difference between IGSN 71 values and adopted absolute gravity values.

Potsdam datum correction of - 14.0 mgal incorporated in the IGSN 71 values. The IGSN 71 standard reflects control from 1200 relative gravity pendulum measurements as well as the 10 absolute gravity values used.

As brought out in Figure 2, the IGSN 71 gravity values do not provide a good overall fit to the adopted absolute values and any best fit to the differences in values would define a slope even if the questionable absolute gravity value at Bogota is disregarded. This is true also if the site to site interval (Δg) values or their summations ($\Sigma\Delta g$) are used.

That the Teddington value should plot anomalously low in Figure 2 is surprising in that it is one of the five sites (Boston, Middletown, Washington, Paris, Teddington) where the absolute gravity value should be well determined. One would therefore expect the departure in the IGSN 71 value from the absolute value at Teddington to line up with the departures indicated at Paris, Boston, Middletown and Washington. One explanation for why it doesn't is that the relative pendulum measurements used in the IGSN adjustment (Teddington to Washington and Teddington to Paris) introduced a negative bias in the IGSN 71 adjusted Teddington value. Another explanation could be that the transfer interval of -0.07mgal from Teddington site 'E' (the absolute site) to Teddington 'A' (the pendulum site) was in error. Another possible explanation is that the Teddington absolute determinations incorporate a hidden environmental factor. A fourth possible explanation is that the anomalous relation at Teddington is a product of the IGSN 71 adjustment procedure used.

In order to try and focus on the source of the problem represented at Teddington, relative gravity pendulum observations will be compared with the absolute gravity intervals between Washington and Teddington and between Paris and Teddington. These pendulum data may differ somewhat from those used in the IGSN 71 adjustment in that the observed values after making all standard corrections are corrected for pendulum period creep (drift) and tares (jumps in period) brought out by the closures for the ladder sequence (A-B-C-D-C-B-A) in which the observations were made. To illustrate the procedure employed the data obtained with the Gulf-Wisconsin compound quartz pendulums in 1963 (unpublished) between Madison, Wisconsin, Washington, Teddington and Rome will be used. The reason for including the entire sequence of observations rather than just the Washington-Teddington interval is to demonstrate the reality of the pattern of pendulum period creep that characterized this series of observations. In order to establish whether the creep defined by the closures was the same on the back leg as the going leg, the IGSN 71 values will be used as an independent set of values to define how the closure pattern developed. As there should be no significant bias in the IGSN 71 gravity standard over the 1080-mgal range involved, the use of the IGSN 71 values should not bias in any way the pendulum results since they do not enter numerically at any point into the determination of the final pendulum values.

As the series of pendulum observations was interrupted for a Potsdam connection from Teddington on both the going and back legs, and a closed loop of observations was made in Africa between the first and second Rome occupation, the equivalent of overnight 'layover' corrections when using gravimeters is required to establish the sequence values at both Teddington and Rome. The basic data with an arbitrary value for Madison, Wisconsin, the starting and closing point for the sequence, are given in Table 4 along with the layover corrected values, closures and IGSN 71 comparison values. In Figure 3-A the layover corrected pendulum values (column (3) of Table 4) are plotted as a function of the sequence interval for closures relative to the sequence end point (Rome). Sequence interval is used rather than time,as pendulum creep is a function of pendulum knife edge wear and therefore only related to use. As seen, the closure plot indicates a uniform creep rate of 0.2 mgal per observation. The IGSN 71 values comparison plot (Figure 3-B), on the other hand, indicates that there was only creep on the going leg from Madison to Rome and that there was no creep on the back leg from Rome to Madison. Neither plot indicates any tares (jumps in values). The apparent 0.2-mgal per observation creep rate indicated throughout the sequence by the closure plot, therefore, is a result of there having been actually 0.4 mgal per observation creep on the going leg and zero creep on the back leg. This fact could not have been established if there had not been the comparative data to define how the closure pattern developed, and it is for this reason that a comparison series of gravimeter measurements is always taken along

Table 4

Pendulum Data Madison-Washington-Teddington-Rome

Obs.No	Sequence No.	Site	(1) Observed	(2) Layover Corr. mgal	(3) (1)+(2) Corr.Value	(4) Closure	(5) IGSN 71	(6) (3)-(5) Diff. mgal
1	1	Madison 'A'	980,369.25		0,369.25	+1.27	0,354.22	+15.03
2	2	Washington 'D'	980,101.56		0,101.56	+0.68	0,086.05	+15.51
3	3	Teddington 'A'	981,197.74		1,197.74	+0.37	1,181.78	+15.96
11		" "	981,197.26	(Δ-0.48) +0.48	1,197.74			
12	4	Rome 'A'	980,365.03	+0.48	0,365.51	0.0	0,349.23	+16.28
26		" "	980,364.79	(Δ-0.24) +0.72	0,365.51			
27	5	Teddington 'A'	981,197.39	+0.72	1,198.11		1,181.78	+16.33
30		" "	981,197.92	(Δ+0.53) +0.19	1,198.11			
31	6	Washington 'D'	980,102.05	+0.19	0,102.24		0,086.05	+16.19
32	7	Madison 'A'	980,370.33	+0.19	0,370.52		0,354.22	+16.30

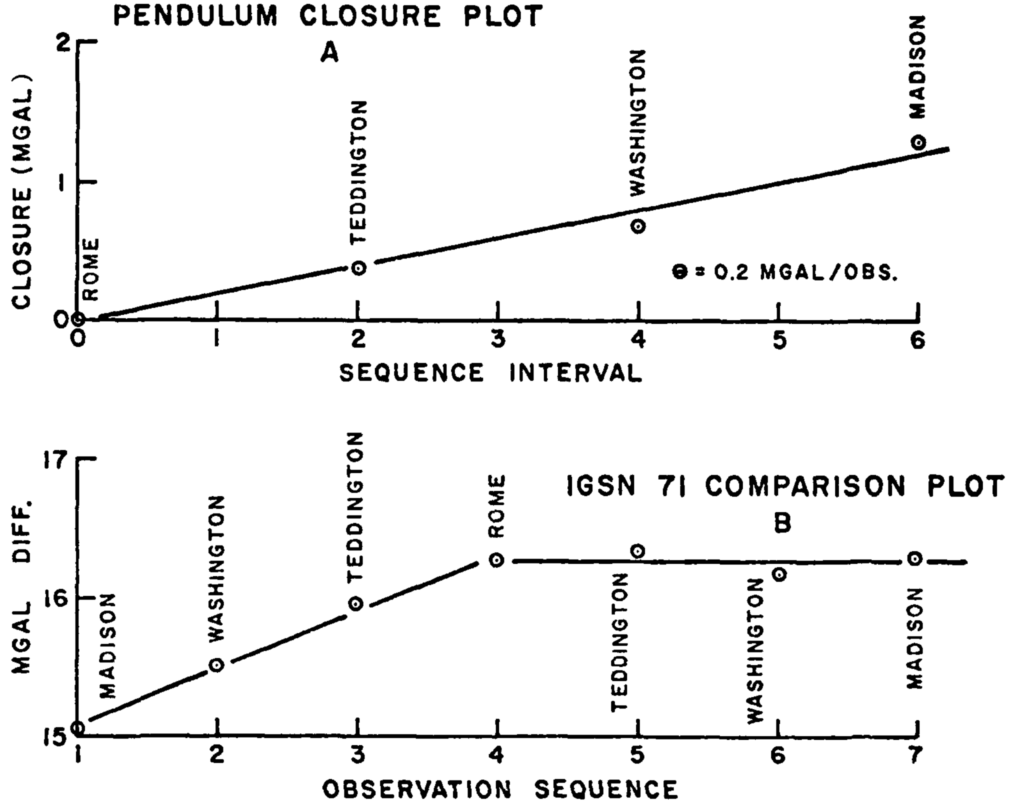


Fig.3. A - Plot of pendulum closure values Madison- Washington- Teddington- Rome.
B - Plot of comparison of pendulum values and IGSN 71 values Madison- Washington- Teddington- Rome.

with pendulum measurements. In this case, though, the IGSN 71 values have been used to demonstrate the role of the comparative data.

In Table 5 the creep corrected pendulum values are given and the final value taken as the average of the two creep corrected values determined at each site. As is obvious from an inspection of the data shown in Table 5, there would have been a significant difference in values if the uncorrected original layover corrected values had been used or if a single creep rate, as suggested by the closure plot, had been used.

If the final creep corrected values from Table 5 are reordered in terms of decreasing gravity, and the site to site gravity intervals are compared on the same basis with the IGSN 71 values, the results are as shown in Table 6. The pendulum data in Table 6, however, require one additional correction to be truly comparative with the absolute and IGSN 71 values. This is the addition of the Honkasalo (1964) earthtide latitude correction term. This correction amounts to +0.031 mgal at Teddington and +0.007 mgal at Washington. Inclusion of this correction would raise the pendulum gravity interval by 0.02 mgal between Teddington and Washington to give a gravity interval of 1095.85 mgal and indicate a discrepancy of -0.12 mgals in the IGSN 71 gravity interval. This discrepancy is close to that defined by the absolute measurements, as shown by the comparative data of Table 7. In this table the Teddington-Washington pendulum gravity interval is corrected by 15.27 mgal for the site transfer from Washington 'D', the pendulum site, to Washington 'V', the absolute gravity site. In order to avoid bias the correction is based on the IGSN 71 values of Morelli et al.(1974) for the Washington excenters.

Table 5

The Final Pendulum Values

Sequence No.	Site	Layover Corr.Values	Creep Corr. -0.40/obs mgal	Corr.Values	Avg. Values
1	Madison 'A'	980,369.25	0.0	0,369.25	980,369.285
2	Washington 'D'	980,101.56	-0.40	0,101.16	980,101.100
3	Teddington 'A'	981,197.74	-0.80	1,196.94	981,196.925
4	Rome 'A'	980,365.51	-1.20	0,364.31	980,364.310
			0.0/obs		
5	Teddington 'A'	981,198.11	-1.20	1,196.91	
6	Washington 'D'	981,102.24	-1.20	1,101.04	
7	Madison 'A'	980,370.52	-1.20	0,369.32	

Table 6

Comparison of Final Pendulum Interval Values and IGSN 71 Interval Values

Site	Avg. Pendulum	$\Sigma\,\Delta g$	IGSN 71	$\Sigma\,\Delta g$	Diff.Pend IGSN 71 $\Sigma\,\Delta g$
Teddington 'A'	981,196.925		981,181.78		
	Δg (-827.64)	- 827.64	(-827.56)	- 827.56	-0.08
Madison 'A'	980,369.285		980,354.22		
	Δg (-4.98)	- 832.62	(-4.99)	- 832.55	-0.07
Rome 'A'	980,364.310		980,349.23		
	Δg (-263.21)	-1095.83	(-263.18)	-1095.73	-0.10
	H.corr.	.02*			
Washington 'D'	980,101.100	-1095.85	980,086.05		

* Honkasalo (1964) earthtide correction on Teddington-Washington interval

Table 7

Comparison of Absolute, Relative Pendulum and IGSN 71

Gravity Intervals between Teddington and Washington

	Absolute Value	Pendulum Δg	IGSN 71	IGSN 71 Rel.Abs
Teddington 'A'				
Cook	981,181.840			
Hammond and Faller	981,181.891			
Avg.	981,181.866		981,181.78	-0.086
		-1095.85		
Washington 'D'				
		+ 15.27		
Washington 'V'				
Hammond and Faller	980,101.271	———	980,101.32	+0.049
Avg. Δg	-1,080.595	-1,080.58	-1,080.46	-0.135
Hammond and Faller	-1,080.620			-0.160

The data of Table 7 indicate that any uncertainty in the absolute gravity site transfer correction at Teddington from site C to site A is probably no greater than 0.01 mgal, and since the pendulum interval value agrees so closely with the absolute gravity interval value, that there is no hidden environmental effect incorporated in the Teddington absolute determination. These conclusions are verified by an additional round trip gravity connection made in 1959 with the Gulf-Wisconsin pendulums between Washington and Teddington, which gives an interval of -1080.56 mgal incorporating the Honkasalo earth tide correction and corrected to the Washington absolute gravity site. This value agrees to 0.02 mgal with that defined by the 1963 measurements used to illustrate the method for determining pendulum creep and correcting for it. Both sets of pendulum data indicate that the gravity interval is within 0.035 mgal of the absolute gravity interval as defined by the average of Cook's and Hammond's absolute measurements.

As using averaged pendulum values uncorrected for creep and tares would give a larger, rather than a smaller gravity interval between Teddington and Washington, the low IGSN 71 gravity interval, therefore, appears to lie in the adjustment procedure used in determining the IGSN 71 values.

In terms of the Paris to Teddington connection there is only one pendulum connection and this involves both pendulum creep and a tare. Corrections for these perturbations gives an interval of +255.87 mgal . How this interval value compares with the absolute and IGSN 71 values is shown in Table 8. As in the case of the Washington to Teddington connection, the IGSN 71 interval is smaller than that indicated by the absolute and

Table 8

Comparison of Absolute, Relative Pendulum and IGSN 71

Gravity Interval Values Paris-Teddington

	Absolute Value	Pendulum Δg	IGSN 71	IGSN 71 Rel.Abs.
Paris A				
BIPM, Sevres Sakuma	980,925.957			
Hammond and Faller	980,925.986			
Average	980,925.972		980,925.97	-0.002
Teddington A Cook	981,181.84			
Hammond and Faller	981,181.891			
Average	981,181.866		981,181.78	-0.086
Avg. Interval	+255.894	+255.87	+255.81	-0.084
Hammond and Faller	+255.905			-0.095
Sakuma and Cook	+255.883			-0.073

relative pendulum gravity measurements.

All of the comparative data examined, therefore, indicate that the IGSN 71 value for Teddington incorporates a real error relative to both Washington and Paris. Although the amount of error is small--0.12 to 0.135 mgals in 1080 mgal (Washington to Teddington) and 0.06 to 0.08 mgal in 256 mgal (Paris to Teddington), or on average 0.18 to 0.27 mgal per 1000 mgal change using just the data for Washington, Teddington and Paris--it exceeds the uncertainty of $\pm$ 0.03 to 0.05 mgal for the absolute measurements that agree on an interval basis to 0.02 mgal with the relative pendulum gravity data.

The apparent overall slope seen in the comparison of IGSN 71 and absolute values (Figure 2) is much less than indicated above between Washington, Paris and Teddington and only about 0.03 mgal per 1000 mgal, indicating that whatever error is incorporated in the IGSN 71 adjustment for Teddington, Paris and Washington is in large measure compensated through the inclusion of the other absolute gravity values. The important thing at this time is to know that there is some foundation for questioning the absolute reliability of the IGSN 71 gravity standard and to pinpoint its probable source for future investigation. This, as brought out here, appears to lie in either the adjustment procedure used or the data other than the absolute values which were utilized in establishing the IGSN 71 gravity standard and values.

THE POTSDAM DATUM CORRECTION

As mentioned earlier, the Potsdam datum correction incorporated in the IGSN 71 values is -14.0 mgal. The reliability of this correction can be evaluated by Woollard's (1963) gravimeter connections to Potsdam from Teddington and indirectly from Paris as well as by two series of measurements made to Potsdam from Teddington using the Gulf-Wisconsin pendulums (unpublished). Although there have been other modern gravimeter connections to Potsdam, only the writer's connections will be used since these data only will be used primarily to evaluate the reliability of the relative gravity pendulum connections.

The Potsdam correction is not a precise value, but rather is rounded off to the nearest milligal, a consequence of three things. The first is that it was not possible following World War II for any Western scientist to obtain permission to make a gravity connection to Potsdam until 1961 when the late Prof. Tano Honkasalo made an indirect connection from Teddington via Helsinki using the Cambridge pendulums (unpublished). In the writer's case it was not until 1963 that permission was obtained to go to Potsdam with gravimeters (Woollard,1963) and later with the Gulf pendulums (unpublished). The second thing is that the Potsdam absolute site is characterized by an anomalous magnetic field as a consequence of a steel heat diffusion shield around the site and a steel floor. This shield has a variable effect, depending upon the degree of degaussing of instruments employing ferro-magnetic systems such as the Cambridge pendulums and LaCoste and Romberg gravimeters. The third thing is the uncertainity in the correction from the points of absolute measurements to the reference pier.

To illustrate the reality of the effect of the locally disturbed magnetic field at the Potsdam Geodetic Institute on gravity values, the difference in free air gravity gradient between observation sites with different elevations in the Institute as determined with gravimeters having ferromagnetic and non-ferromagnetic elements will be used. Over an elevation difference of approximately 5 meters involving four sites, the writer determined the free air gradient to be 0.267 mgal per meter using a Worden gravimeter. With a LaCoste Romberg gravimeter at the same sites and at the same time, the gradient indicated was 0.275 mgal per meter. Reicheneder (1959) of the Potsdam Geodetic Institute, using an Askania meter and at the same sites plus others, defined the free air gravity gradient as being 0.2752 mgal per meter. The overall scatter in values with each instrument does not exceed 0.01 mgal in defining a best fit to the observations, resulting in the close agreement of the Askania and the LaCoste-Romberg gravimeters; thus the lower free air gradient defined with the Worden gravimeter having a non-magnetic quartz system is appreciable, and becomes a source of error when a reliability of the order of 0.01 mgal is being sought for gravity connections. In recognition of this effect on a regional scale, a Helmholtz coil is used with the Cambridge Invar pendulums to provide a constant nulled magnetic field at all observation sites.

For present purposes the value established by Reicheneder (1959) for the Potsdam reference pier (981,274.15 mgal) will be used since any potential error in this value, estimated to be of the order of 0.03 to 0.05 mgal (Woollard, 1963), is of little significance in defining the Potsdam correction.

As both of the Teddington to Potsdam pendulum gravity connections were affected by tares on one leg on the basis of the closures and the gravimeter comparisons, and no creep correction was possible without introducing bias from the gravimeter measurements, only the two apparently more correct (uncorrected) pendulum values are used. These values plus the relative gravity pendulum connections between Washington and Teddington and Paris and Teddington, in conjunction with the modern absolute gravity determinations at Washington, Teddington and Paris, make it possible to evaluate the reliability of the -14.0 mgal datum correction for Potsdam.

The pendulum observations were made on the Pendel-Saal site 7 pier at Potsdam, so a site transfer correction is required. The value used (1.24 mgal) is based on the multiple gravimeter connections made between the pendulum observation site to the absolute reference pier (site 1a). As the reliability of the pendulum connection to Potsdam from Teddington as well as that from Teddington to Paris can be gauged from the gravimeter values from three gravimeters involving four connections between Teddington and Potsdam, these data are included for comparison. The pertinent data are given in Table 9 along with the IGSN 71 values.

Although as seen from Table 9 the average gravimeter interval between Potsdam and Teddington agrees to within 0.01 mgal with the IGSN 71 interval value, the pendulum data indicate that the interval should be about 0.08 mgal lower than the IGSN 71 interval value. As the difference between the IGSN 71 value for Potsdam on the reference pier (981,260.19 mgal) and the old reference value of 981,274.15 mgal is -13.96 mgal, the discrepancy indicated by the comparative data of Table 9

Table 9

Evaluation of the IGSN 71 Potsdam Datum Correction Relative to Teddington

	IGSN	ΣΔg	LRG-1 (Δg) ΣΔg	W-607 (Δg) Σ Δg	LRG-1(2) (Δg) Σ Δg	LRG-7 (Δg) ΣΔg	Avg. Gr.value Adopted	Pend(I)	Pend(II)	Avg.Pend
Potsdam 'A' Ref.Pier Sta.	981,260.19	0.0								
	Δg(+1.20)		(+1.25)	(+1.22)	(+1.26)	(+1.20)				
Potsdam 'G' Pend.Pier S7	981,261.39	+ 1.20	+1.25	+1.22	+1.26	+1.20	+1.24	+1.24	+1.24	+1.24
	Δg (-4.30)		(-4.33)	(-4.31)	(-4.33)	(-4.37)				
Potsdam 'L' E. Berlin AP	981,257.09	- 3.10	-3.08	-3.09	-3.07	-3.17	-3.09			
	Δg(-321.75)		(-322.03)*	(-322.04)*						
Paris 'L' Le Bourget AP	980,935.34	-324.85	-325.11	-325.13						
	Δg (-9.37)		(-9.32)*	(-9.32)*						
Paris 'A' BIPM (Avg)	980,925.97	-334.22	-334.43	-344.45						
	Δg(+259.61)		(+259.67)	(+259.62)	(-71.51)	(-71.51)				
Teddington 'J' London AP-(1)	981,181.58	+74.61	-74.76	+74.83	-74.58	-74.68	-74.71			
	Δg (-3.80)		(-3.68)	(-3.56)	(-3.84)	(-3.76)	(-3.71)	(-79.53)	(-79.61)	(-79.57)
Teddington 'A' NPL (Avg)	981,181.78	+78.41	+78.35	+78.39	-78.42	-78.44	-78.42	-78.29	-78.37	-78.33

* Different site at Le Bourget Airport from that used for IGSN 71 value.

relative to Teddington is less than 0.1 mgal.

To further check this value for the Potsdam datum correction, the absolute values and pendulum interval values between Washington and Teddington, and between Paris and Teddington can also be used with the Teddington to Potsdam pendulum connection to define the correction relative to the Washington, Paris and Teddington absolute values. As the pendulum data incorporate the 1959 pendulum interval value between Washington and Teddington as well as the 1965 value, the interval value is 0.01 mgal less than that given in Table 7. Otherwise all of the values are as brought out in Tables 7,8 and 9. The combined data are given in Table 10. A recapitulation of the data in Table 10 indicates the following:

(old value)	(1) Absolute Δg mgals	(2) Pend Δg mgals	(3) (1-2) mgals	(4) IGSN 71 Δg mgals	(5) (1-4) mgals
Potsdam 'A' - Washington 'V'	- 1172.879*	-1158.90	-13.979	-1158.87	-14.009
Potsdam 'A' - Teddington 'A'	- 92.284*	- 78.33	-13.954	- 78.41	-13.874
Potsdam 'A' - Paris 'A'	- 348.178*	- 334.20	-13.978	- 334.22	-13.958
Average Potsdam correction		Avg.	-13.970	Avg.	-13.947

* Based on Potsdam reference value of 981,274.15 mgals

The Potsdam datum correction of -14.0 mgal adopted for GRS 67 and IGSN 71 therefore, appears to be substantiated to within 0.03 mgal by the relative gravity pendulum connections between the new absolute gravity sites at Washington, Paris and Teddington. The average value is 13.970 mgal with a spread in values from 13.954 mgal to 13.979 mgal for the three absolute sites. The average correction defined by the IGSN 71 values is 13.947 mgal with a spread in values from 13.847 mgal to 14.009 mgal for the three absolute sites.

Table 10

Pertinent Data for an Evaluation of the Potsdam Datum Correction

Based on the Washington, Paris and Teddington Absolute Gravity Values

	Absolute		PendΔg (Δg) $\Sigma\Delta g$	IGSN 71
Washington 'V' NBS	980,101.271			980,101.32
	Δg(+1080.595)		+1080.57 +	(+1080.46)
Teddington 'A' NPL avg. value	981,181.866			981,181.78
	Δg(-255.894)		-255.87	(-255.81)
Paris 'A' BIPM avg. value	980,925.972			980,925.97
	(+824.701)		+824.71	(+824.65)
Washington 'V'	980,101.271			980,101.32
		NPL-Pot.	+78.33	
Δg	(+1,172.879)	Wash-NPL	+1080.57	(+1158.87)
			+1158.90	
Potsdam 'A' Ref. Pier	981,274.15*			981,260.19
	Δg (-92.284)		-78.33	(-78.41)
Teddington NPL	981,181.866			981,181.78
Potsdam 'A' Ref. Pier	981,274.15*	NPL-Pot	-78.33	981,260.19
		NPL-Paris	-255.87	
	Δg (-348.178)		-344.20	(-344.22)
Paris 'A' BIPM	980,925.972			980,925.97

* Old Potsdam Reference values based on Kuhnen and Furtwangler (1906)

+ Average of 1959 and 1963 measurements

SUMMARY OF THE IGSN 71 POTSDAM DATUM VALUE AND GRAVITY STANDARD

The Potsdam correction of -14.0 mgal incorporated in the IGSN 71 values is essentially correct; however, the gravity standard defined by the IGSN 71 values does not give a good fit to the absolute gravity values adopted. On an overall basis the IGSN 71 standard appears to have a negative bias in that an overall negative slope is indicated relative to the absolute gravity values which is even greater if only the sites (Washington, Middletown, Boston, Paris and Teddington) having what should be the best-determined absolute gravity values are used as a standard for comparison. In particular the IGSN 71 value for Teddington appears to be in error relative to the absolute values and the relative gravity pendulum connections between Washington and Teddington, and Paris and Teddington. The error appears to be in the adjustment procedure used or in the values other than the absolute measurements incorporated in the adjustment.

The degree of error indicated in the IGSN 71 gravity standard on an overall basis (omitting Bogota where the absolute gravity determination was substandard) is about -0.03 mgal per 1000 mgal increase in gravity. Zèro correction would be for an absolute gravity value of about 980.100 mgal, but the IGSN 71 value for Washington, which approximates this absolute value, would be 0.05 mgal high.

Despite the above apparent error in the IGSN 71 gravity standard, which could be rectified through creep and tare corrected relative pendulum data, the IGSN 71 values represent a tremendous advance in standardizing gravity values on a global scale. Certainly the IGSN 71 values represent a big improvement on previous attempts such as by Woollard and Rose (1963). Just as the Woollard and Rose values, which had in general a reliability of $\pm$ 0.3 mgal on a global scale, were adopted for an interim period as being superior to earlier data that had a reliability of no more than $\pm$ 1.0 mgal, the IGSN 71 values, which have an estimated reliability of $\pm$ 0.1 mgal on a global scale, should be adopted until they are superceded by better values. The big forward step represented in the IGSN 71 values is so marked that any future revisions will be of a minor nature and only important for standardization measurements and for a limited number of types of investigation. For example, one can anticipate the need for more precise global gravity values for inter-relating crustal events at widely separated points on the earth and in lunar laser ranging studies of continental drift as well as for secular changes on a continental scale due to regional crustal uplift and subsidence. For such studies a revision of the IGSN 71 would be extremely important. However, as they stand, the IGSN 71 values represent the best values available on a world-wide basis. Further, most of the key gravity data for the world are now consolidated into a single system and for a specific limited period in time. Although there was some evolution in program involved, the key data represented in the IGSN 71 values were taken for the most part within a 5-to 7-year period and with superior instrumentation. By way of a contrast, the Woollard and Rose (1963) data were taken during a a 13-year period of instrumentation development. The significance of this difference is brought out in Figure 4 in which plots are presented showing the difference in gravimeter values obtained at

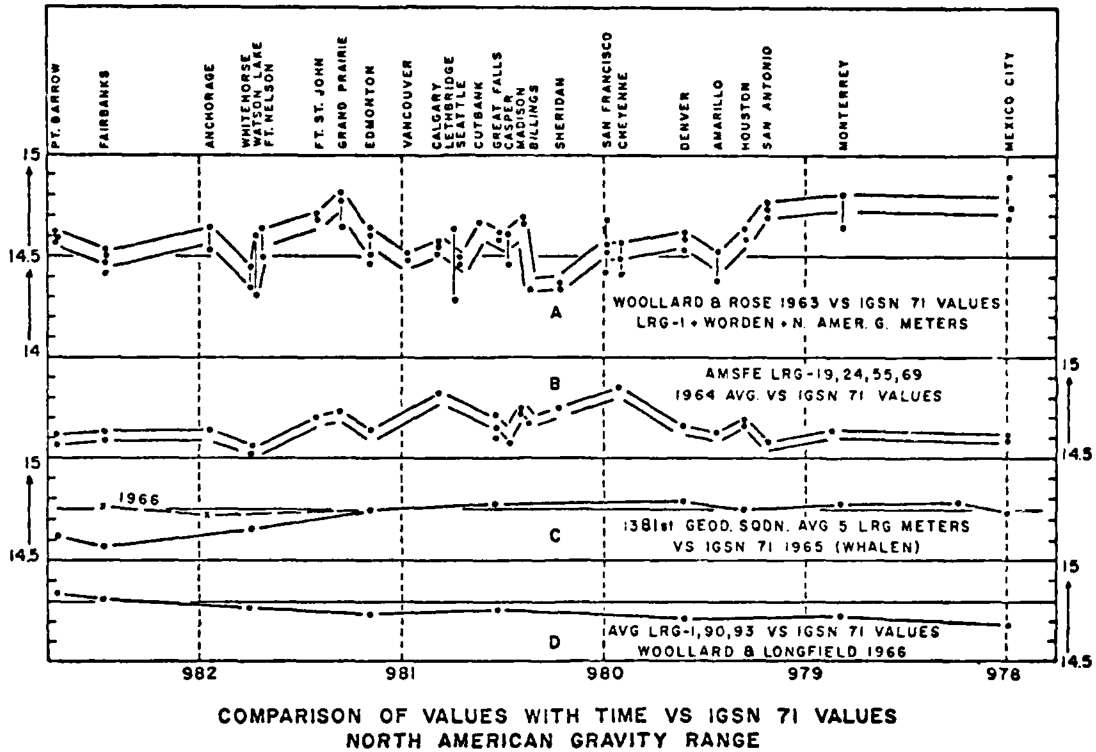


Fig. 4. Effect of improvements in instrumentation and calibration procedures on gavimeter results obtained at pendulum sites on Rocky Mt. Front gravity standardization range Point Barrow, Alaska to Mexico City.
A- Woollard and Rose 1963 values (1948-1962) vs. IGSN 71 values.
B- Army Map Service Far East 1964 values (average 4 La Coste- Romberg gravimeters) vs. ISGN 71 values.
C- Air Force 1381st Geodetic Squadron 1965-1966 (average 5 LaCoste-Romberg gravimeters) vs. IGSN 71 values.
D- Woollard and Longfield (unpublished) 1965 (average 3 LaCoste - Romberg gravimeters) calibrated against pendulum values vs. IGSN values.

different points in time at the pendulum bases and their excenters over the North American gravity standardization range from Point Barrow, Alaska to Mexico City, Mexico. Plot A is for the Woollard and Rose (1963) values which represent averages of data taken during the period 1948 to 1962 with various early high range gravimeters (Humble, North American, Worden and after 1957 with the first geodetic type LaCoste-Romberg gravimeter). On an overall basis no significant difference in gravity standard from that of IGSN 71 is indicated between Point Barrow, Alaska and Monterrey, Mexico. However, it is clear from the spread in excenter values at any one site that the values in general had an uncertainty of $\pm$ 0.1 mgal and that between sites the uncertainty in the reading dial screws limited reliability to $\pm$ 0.2 mgal. The departure in the Woollard and Rose (1963) values from the IGSN 71 values increases progressively south of Houston, Texas as gravity decreases. This is now known to be a consequence of the manufacturer's calibration of the instruments as well as the uncertainty in the pendulum values used to improve the manufacturer's calibration.

That there was improvement in the next generation of gravimeters built by LaCoste-Romberg is brought out in Plot B, which presents the average results (unpublished) obtained by the then Army Map Service, Far East in 1964 over the North American gravity standardization range using four LaCoste-Romberg gravimeters. The spread in excenter values at any one site relative to the IGSN 71 values in this plot is in general only about 0.05 mgal, and although the reading dial screw eccentricity has been reduced somewhat, it is still about $\pm$ 0.15 mgal between sites.

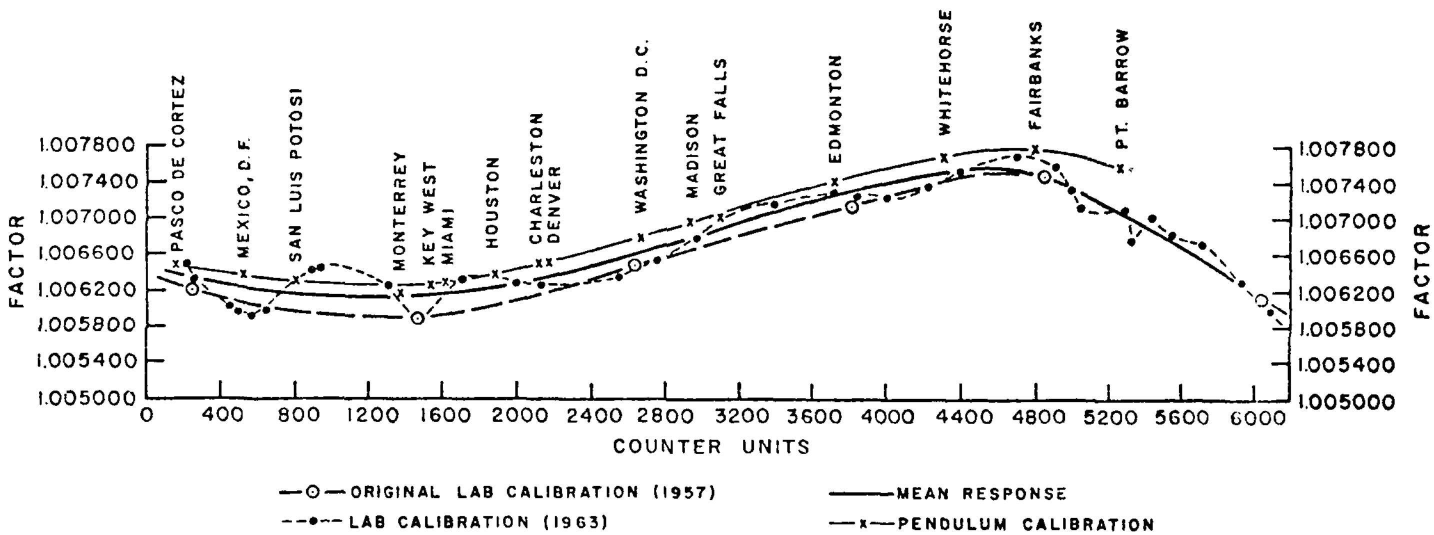
The overall calibration, although good for the end points, departs significantly from the IGSN 71 values in the mid-range region.

In Plot C the average values obtained with five LaCoste gravimeters by the Air Force 1381st Geodetic Squadron (Whalen, unpublished) at the pendulum sites on the North American gravity range are shown relative to the IGSN 71 values. Although fewer sites were occupied than used in Plots A and B it appears that the reading dial screw eccentricity has been reduced to the point that the uncertainty in values is no more than about 0.04 mgal . The calibration also agrees with the IGSN 71 gravity standard except for the sector north of Edmonton, Canada. This defect was removed by a subsequent more complete laboratory calibration as indicated by the 1966 values reported for Anchorage and Fairbanks.

Plot D presents the values obtained by Woollard and Longfield in 1966 (unpublished) using two later-generation LaCoste-Romberg gravimeters and with LRG-1 recalibrated in the LaCoste-Romberg Laboratory using 33 points to establish the screw characteristics as well as the overall calibration, which was adjusted to give a best fit to the pendulum data.

When one considers the difference in site to site values relative to the IGSN 71 values indicated in Plot D(relative to those shown in Plot A in which LRG-1 was also used but with its calibration based on only 11 points in the laboratory covering the entire range of the instrument) the improvement in instrumentation was clearly significant. One other point of interest brought out by Plot D is the difference in gravity standard defined, which is about 0.025 mgal per 1000 mgal greater than that incorporated in the IGSN 71 values. This difference is in the same sign and about the same magnitude as that brought out in Figure 2 in the comparison of IGSN values with the absolute gravity values. Attention is called to this because the overall calibrations of the gravimeters represented in Plot D were based on pendulum values corrected for creep and point out the importance of having any bias in the IGSN 71 values rectified if they are to constitute a reliable gravity standard. Equally as important is the laboratory calibration of gravimeters to be used for long-range gravity connections. This latter point is well brought out in Figure 5 which shows: (a) the difference between the manufacturer's original calibration of LRG-1 using only 11 points in the laboratory calibration to define the overall instrument response and that defined several years later using a 33-point laboratory calibration, and (b) the difference between the mean response as defined by the later calibration and pendulum values covering much of the range of the instrument. As is evident, there is a systematic, essentially linear deviation in the two overall calibrations represented, and as is also evident, this deviation could not have been defined without having a number of pendulum values covering the range of the instrument rather than just the two end points since the instrument response is nonlinear.

With the above points established concerning the IGSN 71 values and their apparent degree of reliability, it is possible to use them as a standard with a probable error at any point not exceeding the $\pm$ 0.1 mgal limitation claimed, at least over a range of about 3500 mgal north and south of Washington, D.C. That is, the IGSN 71 values may well incorporate a bias of about 0.03 mgal per 1000 mgal change, but with zero



COMPARISON OF LABORATORY & FIELD CALIBRATION FACTORS
LACOSTE & ROMBERG G-1

Fig. 5. Difference in laboratory calibration of LRG-1 based on 11 and 33 point laboratory calibration and relation of this calibration to pendulum values.

bias for an absolute gravity value of about 980.100 mgal there will be very few places where this bias would result in values being systematically off by more than 0.1 mgal. A larger source of error will be random discrepancies superimposed on the systematic effects such as that noted for Teddington.

With these limitations in mind, the international gravity values of Woollard and Rose (1963) will be evaluated since they have been used extensively for gravity control, and because it is desirable to convert oil company gravity anomaly maps based on these values and for which the basic data are no longer available to the new GRS 67 - IGSN 71 gravity system. An additional reason for examining the Woollard and Rose values relative to the IGSN 71 values, is that the IGSN 71 values represent the first opportunity for evaluating the global reliability of work done under conditions that would be regarded as unacceptable today.

DIFFERENCE BETWEEN WOOLLARD AND ROSE (1963) AND IGSN 71 GRAVITY VALUES

Because the gravity values published by Woollard and Rose (1963) were worldwide in extent and descriptions were given for the sites occupied, most of the sites have been used for both local gravity control and as gravimeter calibration bases. This last is particularly true of the values for the pendulum observation sites. As a result there are IGSN 71 values for nearly all of the pendulum sites reported by Woollard and Rose as well as their excenters, and quite a few other sites, particularly airports. Although the IGSN values of Morelli et al. (1974) do not include many of the Woollard and Rose airport sites, an independent (unpublished) adjustment to the same standard as IGSN 71 by the Defense Mapping Agency

Aerospace Center does include many of these Woollard and Rose sites not given in Morelli et al. (1974). Between these two sets of adjusted values, about 65 percent of the Woollard and Rose values can be related to the IGSN 71 gravity datum and standard.

In the following comparisons of values only the gravimeter values of Woollard and Rose (1963) at the pendulum sites will be considered, as the gravimeter values show less scatter relative to the IGSN 71 values than do the pendulum values. This can be attributed to the variability of much of the Woollard and Rose pendulum data, which also were taken during a period of instrumentation development involving changes in the pendulum recording and timing systems as well as other modifications to make the pendulums more reliable for global gravity interconnections. In considering the Woollard and Rose gravimeter data, the values at the pendulum sites and their local excenters will be examined first. This will be done on an overall basis by continental areas and also in terms of the individual North-South gravity ranges within each continent. Where gravimeter observations were made at pendulum sites established by others, these data are also included in this section on the gravity standardization values. The value in considering the data on a continent by continent and individual range basis is that it will bring out any shifts in datum as well as changes in standard or quality of the Woollard and Rose values relative to the IGSN 71 values. The Woollard and Rose airport and other values not related to the standardization of gravity will be considered separately. In all the comparisons both the IGSN 71 and DMA-AC adjusted values will be shown since the two do not always agree.

COMPARISON OF WOOLLARD AND ROSE VALUES AND IGSN 71 VALUES AT PENDULUM GRAVITY SITES IN NORTH AMERICA

Tables 11 and 12 present the comparisons of the Woollard and Rose gravimeter values relative to the IGSN 71 and DMA-AC values for the pendulum sites and their excenters in North America. Table 11 covers the gravity standardization range between Point Barrow, Alaska and San Antonio, Texas but includes auxiliary key sites used extensively on the West Coast and in the mid-continent area. Table 12 covers the East Coast gravity standardization range from Ottawa, Canada to Key West, Florida, and also the southern extension of these ranges from Monterrey, Mexico to Panama. In Figure 6 the differences in the Woollard and Rose (1963) values relative to the adjusted values are plotted as a function of absolute gravity. The center point in the plots is the average departure at the site (pendulum site and its excenters) and the spread in the values is indicated by the error bar. In a few cases the latter is exaggerated by having the two standards of comparison. A single point indicates there was only a single comparative value for the site. Because there is a problem in connection with the values south of Mexico City the plot is broken into two segments: Point Barrow, Alaska to Mexico City and, in order to have an overlap of the segments, Houston, Texas to Panama. This last is also desirable as both Houston and San Antonio were used as points of embarcation in making direct ties to Panama and South America as well as Mexico. This latter segment as seen suggests a calibration problem, or else a problem in the IGSN 71 adjustment. As this cannot be resolved at this time, only the Point Barrow-Monterrey segment will be considered. As seen from Figure

Table 11

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values at Pendulum sites and their Excenters in North America

A - Western and Mid-Continent Series

Code: GW - Woollard and Rose pendulum site number (Intl. Gravity Meas. SEG 1963)
Dom. and USCGS: pendulum sites of Dominion Obs. and US Coast and Geod. Survey
WA - Woollard and Rose airport site number (Intl. Gravity Meas. SEG 1963)
WH - Woollard and Rose harbor site number (Intl. Gravity Meas. SEG 1963)
'A', 'B', 'C' - Pendulum or absolute gravity site. Intl. Grav. Bur. Paris
'J', 'K', 'L' - Airport or other excenter site. Intl. Grav. Bur. Paris

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
ALASKA						
	Point Barrow					
GW 105	Arctic Rsch. Lab.	982.6996	"B" .68500	+14.60		
GW 5	" " "	982.6998	"A" .68518	+14.62	.68517	+14.63
WA 280	Airport	982.6998	"K" .68521	+14.59		
	Fairbanks					
GW 6	U of A Geophys. Inst.	982.2462	"A" .23171	+14.49	.23170	+14.50
GW 27	Fort Wainwright	982.2444	"B" .22991	+14.49		
Absolute	Rm 1, Patty Bldg Univ. Alaska	982.2495	"C" .23500	+14.50		
WA 279	Int'l. Airport	982.2464	"K" .23197	+14.43		
WA 347	Ft Wainwright AP	982.2439	"J" .22937	+14.53		
	Anchorage					
USCGS	Elmendorf AFB	981.9400	"A" .92519	+14.81		
WA 474	" "	981.9382	"J" .92356	+14.64		
WA 323	Int'l. Airport	981.9204	"K" .90586	+14.54	.90582	+14.58

(cont.)

Table 11 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
CANADA						
	Watson Lake, Yukon Territory					
Dom. Obs.	Airport manager	981.7150	"A" .70039	+14.61		
WA 476	AP outside term.	981.7143	"K" .69998	+14.32		
	Whitehorse, Yukon Territory					
GW 26	Airport Pump House	981.7486	"B" .73425	+14.35		
WA 188	Airport	981.7487	"J" .73425	+14.45		
	Fort Nelson, British Columbia					
Dom Obs	Hotel	981.6828			.66817	+14.63
WA 182	Airport	981.6929	"J" .67839	+14.51		
	Fort St. John, British Columbia					
GW 27	AP Adm. Bldg.	981.4059	"A" .39121	+14.69		
WA 478	Airport outside term.	981.4055	"J" .39078	+14.72	.39079	+14.71
	Vancouver, British Columbia					
Dom Obs	"	980.9352	"A" .92068	+14.52	.92068	+14.52
WA 186	Int'l. Airport	980.9299	"J" .91541	+14.49		
	Grande Prairie, Alberta					
Dom Obs	Post Office	981.3180	"A" .30322	+14.78	.30320	+14.80
GW 10	School	981.3175	"B" .30285	+14.65		
WA 183	Airport tower	981.3158	"J" .30099	+14.81		
	Edmonton, Alberta					
Pend.	Univ. Alberta	981.1677	"A" .15309	+14.61	.15309	+14.61
GW 25	" "	981.1678	"B" .15316	+14.64		

(cont.)

Table 11 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
GW 5	Univ. Alberta	981.1672	"C" .15279	+14.41		
WA 181	Mun. Airport	981.1729	"K" .15838	+14.52		
WA 282	RCAF NAMAO	981.1803	"M" .16584	+14.46		
	<u>Calgary, Alberta</u>					
GW 32	AP Generator Bldg	980.8281	"A" .81355	+14.55		
WA 180	Terminal	980.8288	"J" .81425	+14.55		
Dom Obs	Public Library	980.8286	"C" .81406	+14.54	.81406	+14.54
	<u>Lethbridge, Alberta</u>					
GW 33	Post Office	980.7589	"A" .74462	+14.28	.74461	+14.29
GW 12	Mun. Bldg	980.6083	"C" .74418	+14.12		
WA 184	Airport	980.7538	"J" .73915	+14.65		
	UNITED STATES					
	<u>Seattle, Washington</u>					
GW 104	Univ. Wash.	980.7388	"A" .72434	+14.46	.72434	+14.46
WA 170	Int'l. Airport	980.7765	"K" .76202	+14.48		
	<u>Cutbank, Mont.</u>					
GW 34	Airport	980.6085	"B" .59383	+14.67	.59377	+14.73
	<u>Great Falls, Montana</u>					
GW 4	Roosevelt Sch.	980.5269	"A" .51230	+14.60	.51229	-14.59
WA 482	Mun. Airport	980.5137	"J" .49911	+14.59		
WA 243	Malmstrom AFB	980.5291	"K" .51452	+14.58		

(cont.)

Table 11 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
	Billings, Montana					
GW 25	AP Hangar	980.3710	"A" .35637	+14.63	.35637	+14.63
WA 122	Terminal	980.3717	"K" .35737	+14.33		
	Sheridan, Wyoming					
GW 36	AP Hangar	980.2264	"A" .21205	+14.35		
WA 179	Field	980.2265	"J" .21214	+14.36	.21214	+14.36
	Casper Wyoming					
GW 37	AP Hangar	979.9558			.94133	+14.47
WA 177	Field	979.9562	"J" .94159	+14.61		
	Cheyenne, Wyoming					
GW 38	AP Cafe	979.7006	"A" .68618	+14.42	.68619	+14.41
GW 17	Hangar	979.7008	"B" .68630	+14.50		
WA 178	Field	979.7008	"J" .68623	+14.57		
	Denver, Colorado					
Absolute	Univ. Denver	979.6123	"A" .59768	+14.62	.59770	+14.60
GW 39	Chamberlain Obs.	979.6117	"B" .59710	+14.60		
WA 89	Stapleton Field	979.6335	"J" .61897	+14.53		
	San Francisco, California					
GW 54	Golden Gate Park	979.9867	"A" .97213	+14.57		
WA 87	Int'l. Airport	979.9885	"J" .97381	+14.69		

(cont.)

Table 11 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
WA 86	Int'l. Airport	979.9883	"K" .97375	+14.55		
WA 202	Travis AFB	978.9898	"P" .97538	+14.42		
	Huron, South Dakota					
GW 24x	Hangar (USCG 1200)	980.4530			.43859	-14.41
	Madison, Wisconsin					
GW 31	Univ. Wis. Sci. Hall	980.3689	"A" .35422	+14.68	.35422	-14.68
WA 76	Truax Field	980.3725	"J" .35782	+14.68		
	Chicago, Illinois					
GW 23	Midway AP Hangar	980.2873	"A" .27262	+14.68		
WA 101	Midway Airport	980.2864	"J" .27179	+14.61		
	Beloit, Kansas					
GW 52	Phillips gas sta.	979.9981			.98359	+14.51
	Tulsa, Oklahoma					
GW 51	Univ. Tulsa	979.7661			.75146	+14.64
	Amarillo, Texas					
GW 50	Airport hangar	979.4235	"A" .40911	+14.39		
WA 67	AP Terminal	979.4234	"J" .40887	+14.53	.40887	+14.53
	Houston, Texas					
GW 18	Rice Univ.	979.2983	"A" .28372	+14.58	.23772	+14.58
WA 159	Old Int'l. Airport	979.2932	"J" .27866	+14.64		

(cont.)

Table 11 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
	San Antonio, Texas					
GW 40	Airport storeroom	979.1975	"A" .18273	+14.77		
WA 162	Airport field	979.1976	"J" .18286	+14.74		
WA 161	Airport Terminal	979.1973	"L" .18257	+14.73		

Table 12

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values at Pendulum sites and their Excenters in North America

B - East Coast Series

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
CANADA						
	<u>Ottawa, Ontario</u>					
GWA 53A	Dominion Obs.	980.6208	"A" .60614	+14.66		
GW 53	Geophys Lab.	980.6217	"B" .60710	+14.60		
WA 310	Mun. Airport	980.6187	"L" .60414	+14.56		
UNITED STATES						
	<u>Woods Hole, Massachusetts</u>					
GW 77	WH Ocean. Inst.	980.3273				
GW 77A	" " BM	980.3271			.31249	+14.81
WA 472	Hyannis Airport	980.3400			.32541	+14.59
	<u>Palisades, New York</u>					
GW 1	Lamont-Doherty	980.2596				
WA 133	Kennedy Airport	980.2261	"K" .21135	+14.75	.21134	+14.76
WA 132	LaGuardia Airport	980.2825	"S" .26777	+14.73		
	<u>Princeton, New Jersey</u>					
GW 7S	Univ. Guyot Hall	980.1783	"A" .16373	+14.57		
GW 78A	Rm 14 Guyot	980.1776	"B" .16306	+14.54		

(cont.)

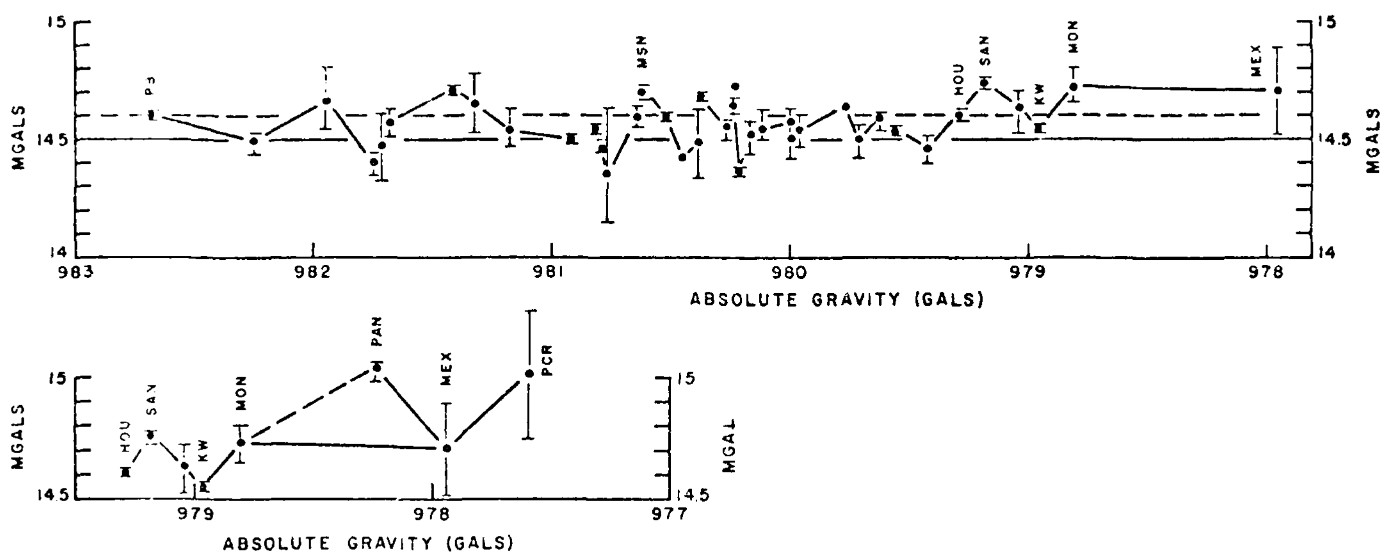
Table 12 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
Absolute	Palmer Lab.	980.1755	"C" .16098	+14.52		
WA 42	McGuire AFB	980.2128	"J" .19836	+14.44	.19835	+14.45
	Washington, D. C.					
USCGS	Commerce Pier	980.1188	"A" .10429	+14.51	.10430	+14.50
GW 2	Dept. Terr. Mag. CIW	980.1006	"D" .08605	+14.55		
Absolute	Old Bu. Stds.	980.0995	"E" .08486	+14.64		
WA 493	National Airport	980.1089	"K" .09440	+14.50		
Absolute	Bu. Stds. Gaithersburg Rm. 129, Bldg 202		"V" .10132			
	Charleston, South Carolina					
GW 90	Citadel Univ	979.5509	"A" .53635	+14.55	.53635	+14.55
WA 494	Mun. Airport	979.5667	"J" .55216	+14.54		
WA 148	Mun. Airport BM	979.5668	"K" .55227	+14.53		
WA 147	MATS Term.	979.5675	"L" .55298	+14.52		
	Miami, Florida					
GW 115	U.M. Marine Biol. Lab.	979.0356	"A" .02095	+14.65	.02095	+14.65
WA 278	Int'l. Airport	979.0528	"J" .03829	+14.51		
WA 11	Old EAL Term.	979.0543	"L" .03957	+14.73		
	Key West, Florida					
GW 116	US Naval Sta.	978.9692	"A" .95446	+14.54		
WH 39	" " gate	978.9686	"J" .95407	+14.53		

(cont.)

Table 12 (cont.)

		(1) Woollard and Rose	(2) IGSN 71		1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
C - MEXICO - CENTRAL AMERICA Series							
	Monterey, Nuevo Leon						
GW 21	Inst. Technology	978.8055	"A"	.79069	+14.81	.97069	+14.81
WA 190	Airport	978.8617	"J"	.84705	+14.65		
	Mexico City, D. F.						
GW 43	Univ. Mexico	977.9414	"A"	.92650	+14.90		
GW 41	Tacubaya	977.9419	"O"	.92715	+14.75		
WA 189	Int'l. Airport	977.9701	"J"	.95542	+14.68	.95543	+14.67
WA 489	Int'l. Airport	977.9705	"L"	.95599	+14.51		
	Paso de Cortes						
GW 42	TV station	977.5711	"A"	.55636	+14.74		
GW B	Cortes monument	977.6536	"C"	.63832	+15.28		
PANAMA							
GW 92	Balboa C.Z.	978.2417	"A"	.22670	+15.0		
92C	YMCA	978.2391	"O"	.22400	+15.10		
WA 4014	Tocumen AP	978.2665	"J"	.25144	+15.06	.25144	+15.06
WA 4004	Albrook AFB	978.2427	"S"	.22772	+14.98		
WH 1015	Rodman Navy Base	978.2376	"R"	.22254	+15.06		



COMBINED DATA AT PENDULUM SITES IN NORTH AMERICA RELATIVE TO IGSN 71 VALUES

Fig. 6. Difference between Woollard and Rose (1963) and IGSN 71 gravity values at pendulum sites and their excenters in North America as a function of absolute gravity.

6, the average departures in values for the various sites indicate that on an overall basis there is no significant difference in gravity standard between that defined by the Woollard and Rose values and the IGSN 71 values. An envelope embracing the extreme average values would suggest the Woollard and Rose values have a systematic negative bias of about 0.05 mgal in 3000 mgal However, a visual best fit to all of the average values would suggest a positive bias of about the same degree. In view of these conflicting indications as to the sign of any departure in standard and its small magnitude, the bias is inconsequential, at least between Point Barrow, Alaska and Monterrey, Mexico. As brought out earlier, the plot for the segment south of Houston does appear to define a change in gravity standard on the basis of the Panama and Paso de Cortes values. This in part could be fortuitous as the departure from the IGSN 71 value at Paso de Cortes pendulum site is 14.74 mgal rather than over 15.0 mgal as indicated by the average value including the only IGSN 71 excenter site that appears to be in common with those of Woollard and Rose. However, there is no question about the 15.1-mgal difference at Panama. This is real and could represent a datum shift (tare) in the Woollard and Rose data.

The distribution of differences in the Woollard and Rose values relative to the IGSN 71 values at all pendulum sites in North America does not define a Gaussian distribution using either individual values or average values for each site, as brought out in Figure 7. Both distribution plots indicate a similar degree of skewness. The difference relative to the DMA-AC values, however, does approach a Gaussian distribution, with any tendency toward skewness being opposite from that defined

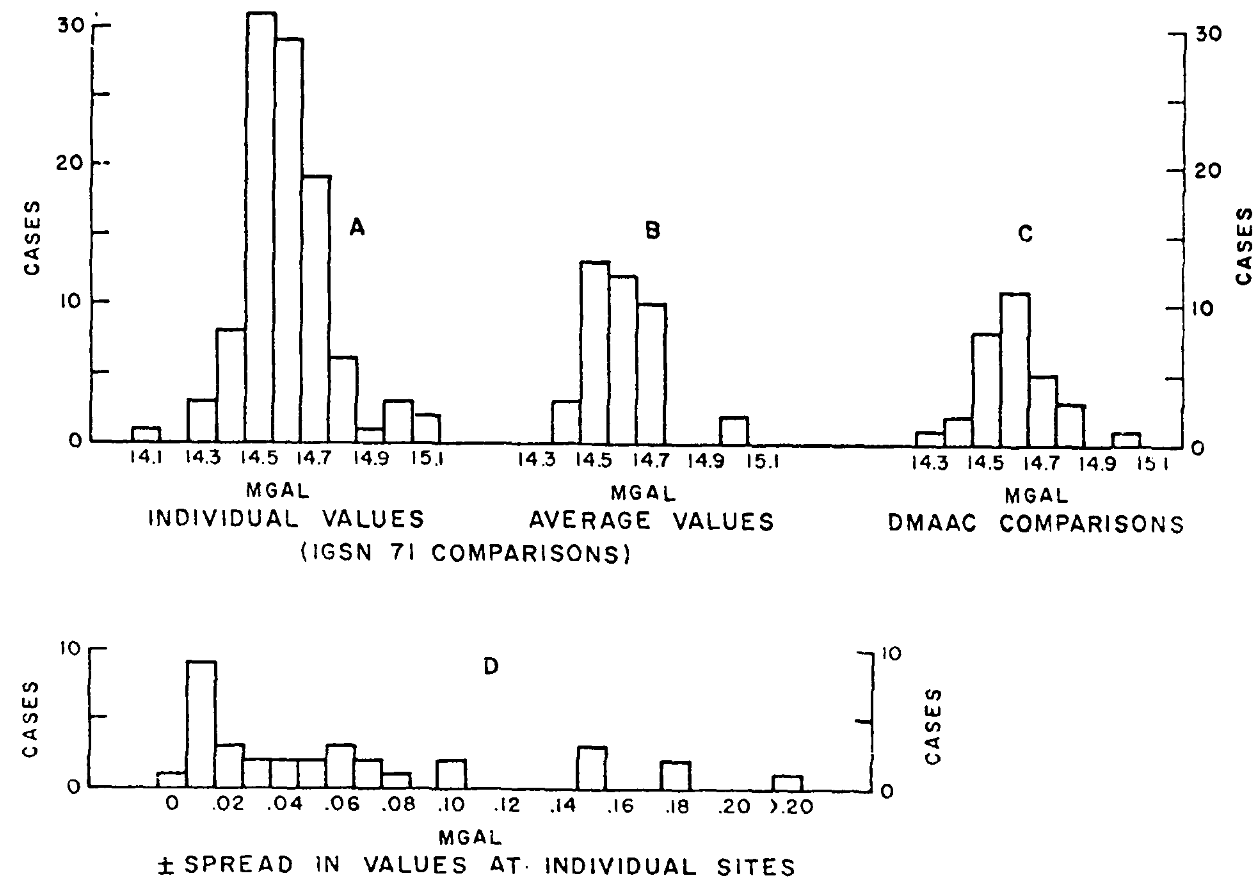


Fig. 7. Distribution plots of differences in Woollard and Rose (1963) and IGSN 71 gravity values at pendulum sites in North America. A - Relative to IGSN 71 values of Morelli, et al. (1974) using individual values; B- Using average values for each site; C - Relative to IGSN 71 values of DMAAC; D - Spread in excenter connections at each site.

by the IGSN 71 values. The mean values for the differences, however, do not differ significantly. For the IGSN 71 comparisons the mean of the individual values is +14.587. The average value is 14.592 mgal. For the DMA-AC comparisons the value is +14.558 mgal . A blanket correction of -14.6±0.1 mgal would therefore appear to apply to about 80 percent of all the Woollard and Rose gravimeter values at the pendulum sites. That the degree of uncertainty in the excenter connections would be significantly less than ±0.1 mgal is brought out by Plot B of Figure 6 in which the spread in differences noted at each pendulum site for the local excenters is shown. The average value using all of the data is ±0.05 mgal , and as is clear from the distribution plot the majority of the values would have even less uncertainty.

A blanket correction of -14.6 mgal , however, would not fit the data equally well for each of the gravity standardization ranges (West Coast, Rocky Mountain Front, Mid-Continent and East Coast) established by Woollard and Rose, as brought out in Figure 8. In this figure plots are shown for the differences in the Woollard and Rose gravimeter values at the pendulum sites relative to the IGSN 71 and DMA-AC IGSN 71 values on each of the above ranges separately, and assuming that each, except for the East Coast range which has lower gravity values at its southern end than the other ranges, might be extended through Houston to Monterrey, Mexico in order to have additional gravity coverage to check the overall laboratory calibration of a gravimeter. For the West Coast series, all values except Monterrey would be within ±0.1 mgal for a datum correction of 14.55 mgal . A correction of 14.55 mgal with the same ±0.1-mgal

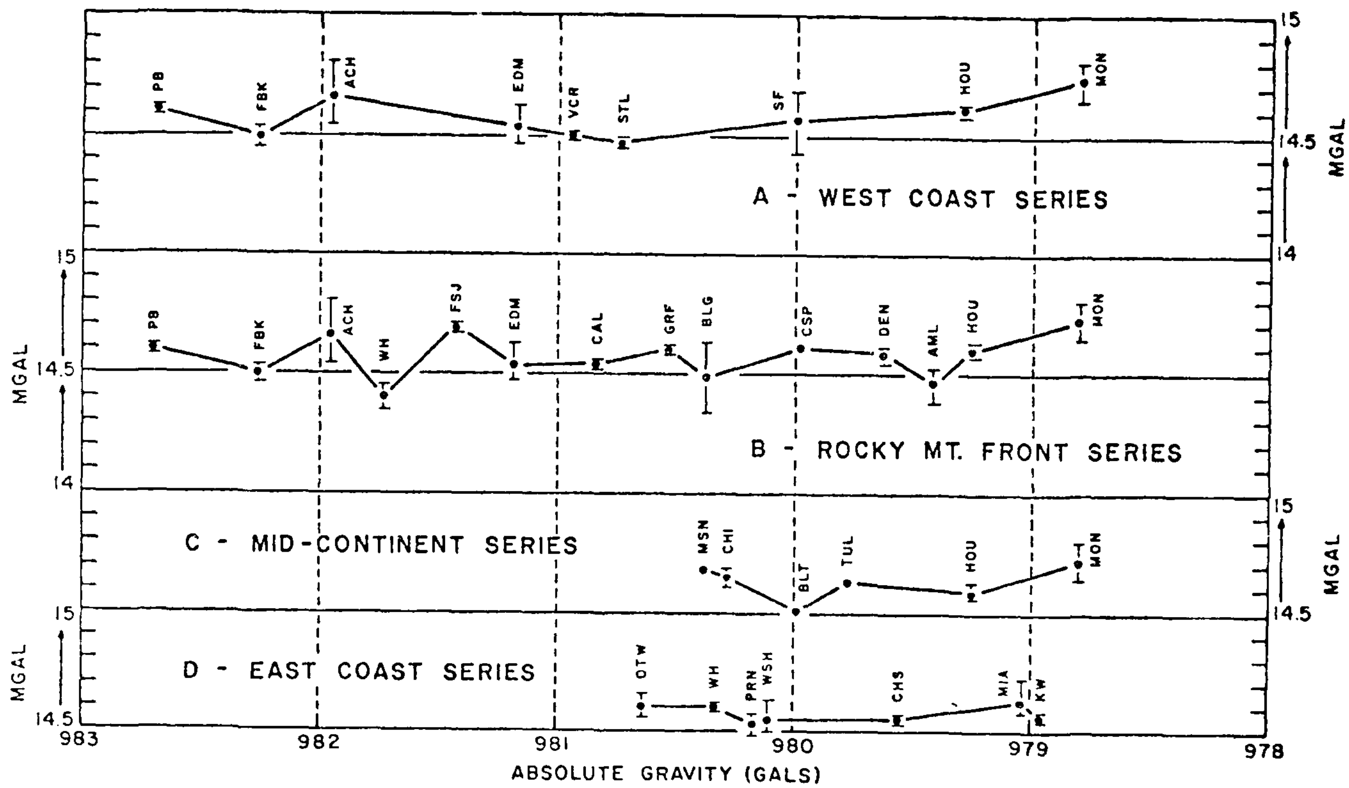


Fig. 8. Difference between Woollard and Rose (1963) and IGSN 71 gravity values at pendulum sites and their excenters in North America on individual gravity ranges. A- West Coast Series; B- Rocky Mt. Series; C- Mid-Continent Series; D- East Coast Series.

uncertainty except for Whitehorse, Fort St. John and Monterrey is indicated for the Rocky Mountain front series. For the mid-continent series the datum correction indicated is 14.6 mgal with the same ±0.1-mgal uncertainty except for Monterrey. For the East Coast series the datum correction is 14.57 mgal with a no more than ±0.05-mgal uncertainty.

In summary it is seen that from the standpoint of the gravity standardization ranges established in North America by Woollard and Rose, their values define a standard on an overall basis which is in agreement with the IGSN 71 gravity standard and within 0.05 mgal as regards the magnitude of the datum correction required to conform to the IGSN 71 datum. In regard to the reliability of the excenter connections to the pendulum observation sites, the reliability on the basis of the IGSN 71 comparisons in general is better than the 0.1-mgal unit used by Woollard and Rose in defining the excenter connections. For the 33 sites for which excenter connections could be evaluated, the ± departures were less than 0.1 mgal from the average value at 27 of the sites. The average for all sites was ± 0.05 mgal and only in one case did the departure exceed 0.2 mgal.

The average datum correction of about -14.6 mgal to the Woollard and Rose values exceeds the -14.0 mgal Potsdam datum correction in the IGSN 71 values, a consequence of the Madison, Wisconsin base value used for the Woollard and Rose values not being based on a direct connection to Potsdam. The Madison value (980.3689 gals) was determined by Woollard (1950) on the basis of relative gravimeter ties with the first geodetic Worden gravimeter to eight international gravity bases that had been tied at various times to Potsdam prior to World War II. This value for Madison was retained since up to the time of publication of the Woollard and Rose values in 1963 no direct gravity ties to Potsdam were possible. However, as brought out in Table 12, the IGSN 71 values indicate a correction of -14.68 mgal at Madison rather than the -14.6 mgal derived here from the 40 pendulum sites considered. This could be related to the ±0.1-mgal uncertainty in the IGSN 71 values.

As Woollard and Rose did not estimate the reliability of their gravimeter values as being better than ±0.3 mgal, the agreement with the IGSN 71 and DMA-AC adjusted values at pendulum sites in North America to within on average ±0.1 mgal of a constant difference of 14.6 mgal is surprisingly good.

COMPARISON OF WOOLLARD AND ROSE GRAVIMETER VALUES AND IGSN 71 VALUES AT PENDULUM SITES IN SOUTH AMERICA

In Tables 13 and 14 the comparison of the Woollard and Rose gravimeter values at pendulum sites and their excenters with the IGSN 71 and DMA-AC adjusted values in South America are given. Table 13 presents the data for the Andean (West Coast) series and Table 14 that for the Atlantic (East Coast) series. In Figure 9 the average and extreme differences in the Woollard and Rose (1963) gravimeter values relative to the adjusted values at each pendulum base site and its excenters are plotted as a function of absolute gravity. The absolute gravity scale is reversed relative to that of Figure 6 in order to maintain a North to South geographical orientation. For purposes of continuity with the North American data the combined data plot includes the data for Paso de Cortes, Mexico

Table 13

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values at Pendulum Sites and their Excenters in South America

A - Andean (West Coast) Series

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
PANAMA						
GW 92	Balboa C.Z.	978.2417	"A" .22670	+15.00		
WA 4014	Tocumen AP	978.2665	"J" .25144	+15.06	.25144	+15.06
GW 92x	Balboa YMCA	978.2391	"O" .22400	+15.10		
WA 4004	Albrook AFB	978.2427	"S" .22772	+14.98		
WH 1015	Rodman Navy Base	978.2376	"R" .22254	+15.06		
COLOMBIA						
GW 106	Bogota IGM	977.4049	"A" .39011	+14.79	.39012	+14.78
Absolute	Bogota Univ. Nac.	977.4049	"C" .39014	+14.76		
WA 6112	AP Mun. Techo	977.4017	"J" .38691	+14.79		
WA 6145	Int'l. AP Eldorado	977.3954	"K" .38059	+14.81		
ECUADOR						
GW 94	Quito	977.2777	"A" .26319	+14.51		
WA 6121	Panagra AP	977.2860	"J" .27144	+14.56		
WA 6139	Mariscal Scure AP	977.2849	"K" .27038	+14.52		
PERU						
GW 93	Lima	978.2830	"A" .26794	+15.06	.26794	+15.06

(cont.)

Table 13 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
WA 6126	Limatambo AP	978.2791	"J" .26408	+15.02		
WA 6140	Callao Int'l. AP	978.3072	"K" .29218	+15.02		
BOLIVIA						
GW 95	La Paz	977.4671	"A" .45219	+14.91	.45221	+14.89
WA 6134	Braniff AP Term.	977.3528	"K" .33800	+14.80		
WA 6020	Panagra Term.	977.3487	"L" .33402	+14.68		
CHILE						
GW 99	Antofogasta	978.9045	"A" .88952	+14.98	.89950	+15.0
WA 6105	Cerro Moreno AP	978.8853	"K" .87030	+15.00		
WA 6135	Old Cerro Moreno AP	978.8830	"L" .86804	+14.96		
GW 96	Santiago	979.4294	"A" .41411	+15.29	.41407	+15.33
WA 6110	Los Cerrillos AP	979.4500	"K" .43468	+15.32		
WH 1020	Valparaiso Pier 1	979.6362	"K" .62087	+15.33		
WH 1058	Valparaiso Lt. Hs.	979.6342	"L" .61890	+15.30	.61887	+15.33
GW 97	Punta Arenas	981.3159	"A" .30049	+15.41	.30052	+15.38
WA 6108	Old Term.	981.3122	"K" .29670	+15.50		
WA 6136	AP Term.	981.3130	"L" .29761	+15.39		
WH 1019	Port Adm. Bldg.	981.3363	"N" .32081	+15.49		

Table 14

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values at Pendulum sites and their Excenters in South America

B - Atlantic (East Coast) Series

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
VENEZUELA						
GW 107	Caracas	978.0399	"A" .02472	+15.18	.02474	+15.16
WA 5131	Maiguetia AP	978.2460	"K" .23106	+14.94		
WH 1071	La Guayra Hrb.	978.2522	"L" .23724	+14.96		
BRASIL						
GW 108	Belem	978.0374	"A" .02224	+15.16	.02223	+15.17
WA 6032	Airport	978.0342	"K" .01897	+15.23		
WH 1012	Tide gage	978.0397	"O" .02459	+15.11		
WH 1055	Pier BM	978.0399	"N" .02463	+15.27		
GW 109	Rio de Janeiro	978.8047	"A" .78990	+14.80	.78990	+14.80
WA 6082	Galeao AP	978.7978	"J" .78305	+14.75		
WA 6081	Santos Dumont AP	978.8084	"L" .79355	+14.85		
WH 1060	Pier Da Praca Nana	978.8076	"O" .79278	+14.82		
ARGENTINA						
GW 98A	Buenos Aires	979.7048	"A" .69003	+14.77	.69003	+14.77
Univ. Base	Meter. Obs.	979.7060	"C" .69116	+14.84		
Univ. Base	La Plata Obs.	979.7517	"O" .73685	+14.85		
WA 6002	Ezeisa AP	979.7317	"K" .71675	+14.95		

(cont.)

Table 14 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
Mateo Pend.	Cordoba Astr. Obs,	979.3419				
WA 6004	Cordoba AP	979.3271	"K" .31234	+14.76	.31232	+14.78
WA 6007	Mar de' Plata AP	980.0181			.00273	+15.37
Mateo Pend.	Hotel Soldini, La Plata	980.0340				
WA 6010	Aeronaval AP	981.2066	"K" .19138	+15.22	.19134	+15.26
Mateo Pend.	Rio Gallegos School	981.2126				
Mateo Pend.	Ushuaia Penitentiary	981.4807	"A" .46539	+15.31		

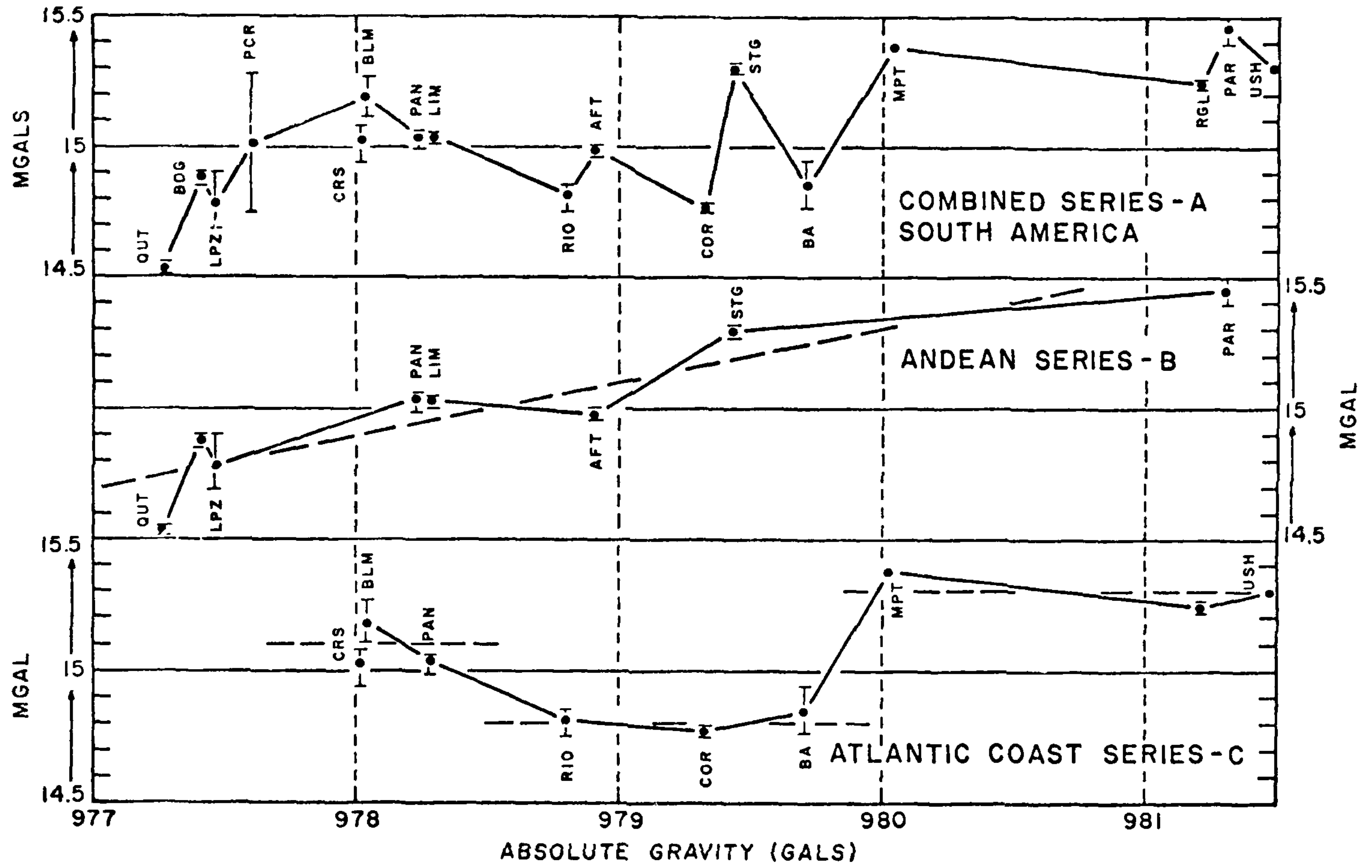


Fig. 9. Difference between Woollard and Rose (1963) and IGSN 71 gravity values at pendulum sites and their excenters in South America. A- Combined Series; B- Andean Series; C- Atlantic (East Coast) Series.

as well as Panama which served as a base for the Woollard and Rose gravity measurements in South America. Three plots are presented. One presents the combined data and the other two are for the Andean and Atlantic series considered separately. The combine data plot indicates an overall significant departure from the IGSN 71 gravity standard of about +0.15 mgal per 1000-mgals increase in gravity. This, as seen, is in large measure related to the Andean series of observations. It, however, is reinforced by what appears to be a datum jump (tare) in the Atlantic series measurements between Buenos Aires and Mar del Plata. As the patterns of the differences in values for the two series differ so significantly, one series is clearly substandard and would appear to be the Atlantic series since a best fit line with a slope of 0.2 mgal per 1000-mgal change would result in an average deviation of only $\pm$0.1 mgal for all of the sites in the Andean series except Quito, which would be off by 0.2 mgal . As any attempt to fit either a slope or a single tare to the Atlantic series of values results in residuals of 0.2 mgal or more for a number of sites, the conversion of these values to the IGSN 71 standard and datum can best be done on a restricted geographical basis using two tares: one of 0.3 mgal between Belem and Rio de Janeiro, and one in opposite sign of 0.5 mgal between Buenos Aires and Mar del Plata. Using these tares all values can be put on the datum of Rio de Janeiro, and a datum correction of -14.81 mgal would convert the series to the IGSN 71 datum and standard since no slopes are involved. For the Andean series the conversion requires both a change in standard and datum. This can be done by using the equation $X = 15.0 + [0.2 \text{ (Woollard and Rose value} - 978.5)]$. Using these two conversion schemes will result in all values being within ± 0.1 mgal of the IGSN values except Quito, which would be off by 0.2 mgal .

COMPARISON OF WOOLLARD AND ROSE GRAVIMETER VALUES AND IGSN 71 VALUES AT PENDULUM SITES IN EUROPE

In Table 15 the comparisons of the Woollard and Rose (1963) gravimeter values with the IGSN 71 and DMA-AC adjusted values at pendulum sites in Europe are given. In Figure 10 the differences between the Woollard and Rose values and the IGSN 71 values are plotted as a function of absolute gravity. In order to define continuity with the African pendulum sites, the values for the pendulum bases at Tripoli and Cairo are also included.

As seen from Figure 10 there are apparent irregular long wavelength changes in the differences in values, which range between +14.55 mgals at Oslo and Lisbon to in excess of +14.95 mgal at Stockholm and Edinburgh. However, the distribution pattern on an overall basis does not indicate that there is any significant difference from the IGSN 71 standard. A mean correction of -14.75 mgal would appear to give a best fit to the data and this is verified by the distribution plots for the difference in individual and average values at each site relative to the IGSN 71 and DMA-AC values. These three distribution plots are shown as part of Figure 10. The individual values, as before, include the excenter values at each site as well as that at the pendulum observation site. The average values, as before, are the average departures for the site (pendulum values and excenters). The DMA-AC values are more restricted in that only a single value is given for each site that, while in most cases is the pendulum site, at times is one of its excenters. The means,

Table 15

Comparisons of Woollard and Rose Gravimeter Values and IGSN 71 Values at Pendulum sites and their Excenters in Europe

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
NORWAY						
GW 118	Hammerfest	982.6324	"A" .61762	+14.78	.61762	+14.78
WH 1045	Indrefjord	982.6301	"J" .61548	+14.62		
GW 117	Bodo	982.3873	"A" .37265	+14.65	.37264	+14.66
WA 5037	Airport tower	982.3876	"J" .37297	+14.63		
GW Pend	Trondheim Phys. Inst.	982.1614	"A" .14674	+14.66	.14672	+14.68
WA 5040	Vaernes AP	982.1523	"K" .13779	+14.51		
GW 68	Oslo (Geol. Mus.)	981.9272	"A" .91261	+14.59	.91261	+14.59
WA 5038	Fornebu AP	981.9307	"J" .91620	+14.50		
FINLAND						
IGM Sta	Helsinki Univ.	981.9152	"A" .90059	+14.61	.90059	+14.61
WA 5019	Sentula AP	981.9248	"S" .91009	+14.71		
SWEDEN						
Kartverk	Stockholm	981.8465	"A" .83143	+15.07		
WA 5053	Bromma AP	981.8455	"J" .83066	+14.84		

(cont.)

Table 15 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
DENMARK						
GW 64	Copenhagen	981.5577	"B" .54319	+14.51		
WA 5004	Kastrup AP	981.5573	"J" .54275	+14.55		
WA 5059	Kastrup AP	981.5568	"L" .54226	+14.54		
WEST GERMANY						
GW 63	Bad Harzburg	981.1803	"A" .16550	+14.80		
GW 63A	Braunshweig Abs.	981.2668	"C" .25184	+14.96	.25183	+14.97
Abs Pier	Potsdam	981.2749	"A" .26019	+14.71		
GW 62	Frankfurt	981.0610	"A" .04632	+14.68		
WA 5028	Airport	981.0571	"J" .04243	+14.67		
ENGLAND						
GW 67	Teddington	981.1966	"A" .18178	+14.82	.18177	+14.83
WA 5012	London AP Term 1	981.2003	"J" .18558	+14.72		
WA 5013	old Term	981.2017	"M" .18704	+14.66		
Camb. Pend.	Cambridge Univ.	981.2688			.25394	+14.86
SCOTLAND						
Camb. Pend.	Edinburgh R. Obs.	981.5839	"A" .56897	+14.93	.56895	+14.95
WA 5047	Prestwick AP	981.5784	"J" .56351	+14.89		
WA 5046	Prestwick MATS	981.5758	"K" .56113	+14.67	.56111	+14.69

(cont.)

Table 15 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
WA 5044	Glascow Renfew AP	981.6018	"N" .58692	+14.98		
Camb·Pend.	Aberdeen, Marischal	981.6998			.68482	+14.98
IRELAND						
Camb. Pend.	Dublin Dunsink Obs.	981.3891			.37478	+14.32
NETHERLANDS						
Pend. Base	DeBilt. R.M.O.	981.2693			.25456	+14.74
WA 5036	Amsterdam AP	981.2882	"J" .27340	+14.80		
FRANCE						
GW 114	Paris (SEVRES)	980.9409	"A" .92597	+14.93	.92596	+14.94
Gm Base	Paris Obs. "A"	980.9434	"B" .92865	+14.75		
Pend. Base	Paris Obs. pier	980.9432	"E" .92829	+14.91		
WA 5058	Orly AP Term.	980.9160	"N" .90101	+14.99		
WA 5024	Le Bourget AP	980.9502	"J" .93534	+14.86		
SPAIN						
Pend. Base	Madrid, Astro. Obs.	979.9812	"A" .96652	+14.68	.96652	+14.68
Gm Base	Madrid IGC	979.9703	"C" .95561	+14.69		
WA 5049	Barajas AP	979.9988	"J" .98414	+14.64		
WA 5051	Torrejon AFB	980.0072	"M" .99251	+14.69		

(cont.)

Table 15 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
PORTUGAL						
GW 110	Lisbon IGC	980.0903	"A" .07573	+14.57	.07571	+14.59
WA 5041	Lisbon AP	980.0796	"K" .06512	+14.48		
SWITZERLAND						
Pend. Base	Zurich Geod. Inst.	980.6670	"A" .65213	+14.87	.65212	+14.88
WA 5055	Kloten AP	980.6871	"J" .67218	+14.92		
ITALY						
GW 61	Rome Univ. Physics	980.3639	"A" .34923	+14.67		
Natl Base	Univ. Fac. Ing.	980.3619	"B" .34722	+14.68		
	Roco de Papa Obs.	980.1929	"C" .17843	+14.47		
WA 5033	Ciampino Est AP	980.3489	"J" .33427	+14.63		
WA 5034	Ciampino Ovest AP	980.3478	"M" .33319	+14.61		
WA 5060	Fiumicino Int'l AP	980.3765	"N" .36176	+14.74		
LEBANON						
LeJay Pend.	Beruit Fac. Med.	979.6909	"A" .67625	+14.65	.67624	+14.66
WA 2050	Khalde AP (a)	979.6934	"J" .67864	+14.76		
WA 2051	Khalde AP (b)	979.6922	"K" .67744	+14.76		

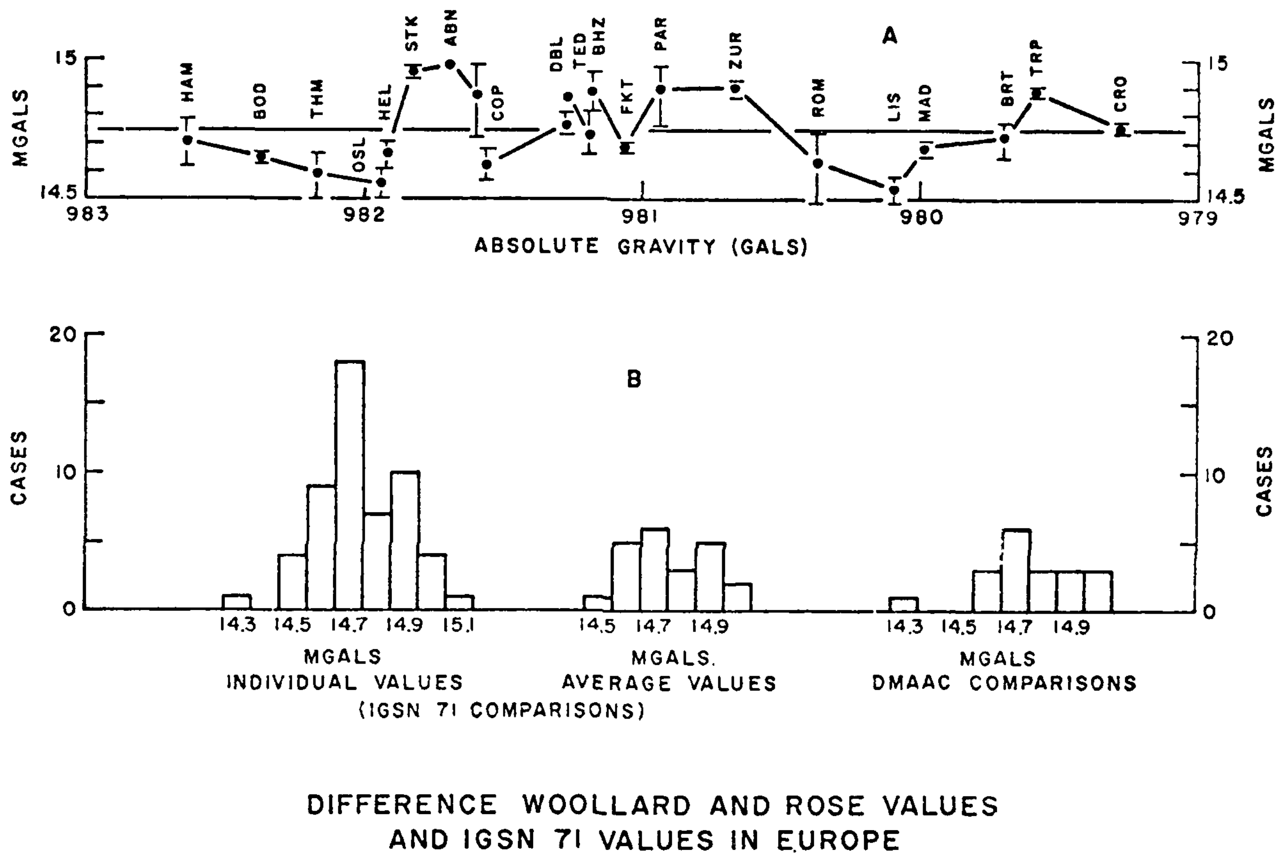


Fig. 10. Difference between Woollard and Rose (1963) and IGSN 71 gravity values at pendulum sites in Europe. A- As a function of absolute gravity; B- Distribution plots of differences.

based on the three distribution plots shown, indicate that relative to the IGSN 71 values the Woollard and Rose values are 14.74 mgal high on the basis of both the individual values and the averaged site values. The DMA-AC data indicate a somewhat higher average deviation of 14.79 mgals. An average correction of 14.75 mgal, therefore, appears to be a reasonable datum correction. However, as is clear from the distribution plots as well as the overall plot, the central portion of the data representing 85 percent of the sites would have discrepancies of up to ± 0.25 mgal.

In summary, the Woollard and Rose values at pendulum sites in Europe, while not indicating on an overall basis any difference in gravity standard from that defined by the IGSN 71 values, require on average a datum correction of -14.75 mgal. However, the quality of the values is such that an uncertainty of up to ± 0.25 mgal would still characterize 85 percent of the values.

COMPARISON OF WOOLLARD AND ROSE GRAVIMETER VALUES AND IGSN 71 VALUES AT PENDULUM SITES IN AFRICA

Tables 16 and 17 give the comparison of Woollard and Rose (1963) gravimeter values at pendulum sites and their excenters in Africa relative to the IGSN 71 and DMA-AC values. Table 16 is for the mid-continent and East Africa series. Table 17 is for the West coast series. In Figure 11 three plots of the data are presented. Section A presents the differences in values for all of the data. Section B is for the mid-continent East Africa series of measurements, and Section C for the West Africa series. In each the differences between the Woollard and Rose values and the IGSN 71 and DMA-AC values are plotted in terms of average values as

Table 16

Comparison of Woollard and Rose Gravimeter Values and IGSN 71 Values at Pendulum sites and their Excenters in Africa

A - Mid-continent Series

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
CYPRUS						
Camb. Pend.	Nicosia	979.8492			.83449	+14.71
LIBYA						
GW 60	Tripoli-Wheelus	979.5876	"A" .57272	+14.88	.57273	+14.87
WA 1021	Idris AP	979.5379	"L" .52300	+14.90		
EGYPT						
GW 69	Cairo Helwan Obs.	979.2915	"B" .27676	+14.74		
WA 1002	Farouk Int'l. AP	979.3160	"L" .30125	+14.75		
ETHIOPIA						
GW 76	Asmara (Kagnew)	977.8194	"A" .80545	+13.95	.80545	+13.95
WA 1005	Mun. AP	977.8224	"J" .80826	+14.14		
SUDAN						
GW 70	Kharthoum Univ.	978.3034	"B" .28867	+14.73		
GW 70A	Univ. pend. site	978.3033	"A" .28864	+14.66		
WA 1045	Airport Term.	978.3034	"L" .28865	+14.75	.28863	+14.77

(cont.)

Table 16 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
KENYA						
GW 71	Nairobi	977.5403	"A" .52607	+14.23	.52607	+14.23
Camb P.	Bullard (1)	977.5279	"C" .51375	+14.15		
WA 1014	Eastleigh AP	977.5430	"J" .52877	+14.23		
WA 1015	West Civil AP	977.5357	"K" .52151	+14.19		
ZAMBIA						
GW 75	Lusaka AP	978.0536	"A" .03929	+14.31		
RHODESIA						
Camb P.	Sailsbury	978.1481	"A" .13365	+14.45	.13363	+14.47
WA 1043	Belvedere AP	978.1484	"J" .13414	+14.26		
SOUTH AFRICA						
GW 73	Johannesburg BPI	978.5495	"A" .53546	+14.04	.53547	+14.03
WA 1062	Jan Smuts AP	978.5503	"K" .53610	+14.20		
Camb P	Pretoria Mus.	978.6296	"A" .61530	+14.30		
GW 74	Capetown, Mowbroy	979.6473	"A" .63271	+14.59	.63271	+14.59
Camb P	Royal Obs.	979.6535	"B" .63893	+14.57		
WA 1051	Malon AP	979.6462	"J" .63145	+14.75		
WA 1056	Wingfield AP	979.6494	"L" .63484	+14.56		

Table 17

Comparison of Woollard and Rose Gravimeter Values and IGSN 71 Values at Pendulum sites and their Excenters in Africa

B - West Coast Series

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
SENEGAL						
GW 111	Dakar. Mbour	978.3852	"B" .37039	+14.81		
WA 1010	Yof AP	978.4772	"J" .46242	+14.78		
GHANA						
GW 112	Accra Univ.	978.1059	"A" .09141	+14.49		
WA 1012	Airport	978.1153	"J" .10052	+14.78		
ZAIRE (Congo)						
GW 113	Kinshasa (Leopoldville)	977.9146	"A" .89982	+14.78	.89984	+14.76
WA 1037	Int'l. AP	977.9518	"J" .93713	+14.67		
WA 1038	Ndjili AP	977.9429	"M" .92820	+14.70		
SOUTH WEST AFRICA						
Camb P	Windhoek	978.3205				
WA 1022	AP Traffic Contr.	978.3210			.30629	+14.71
Camb P	Tsumeb	978.2212				
WA 1070	Airport	978.2209			.20619	+14.71

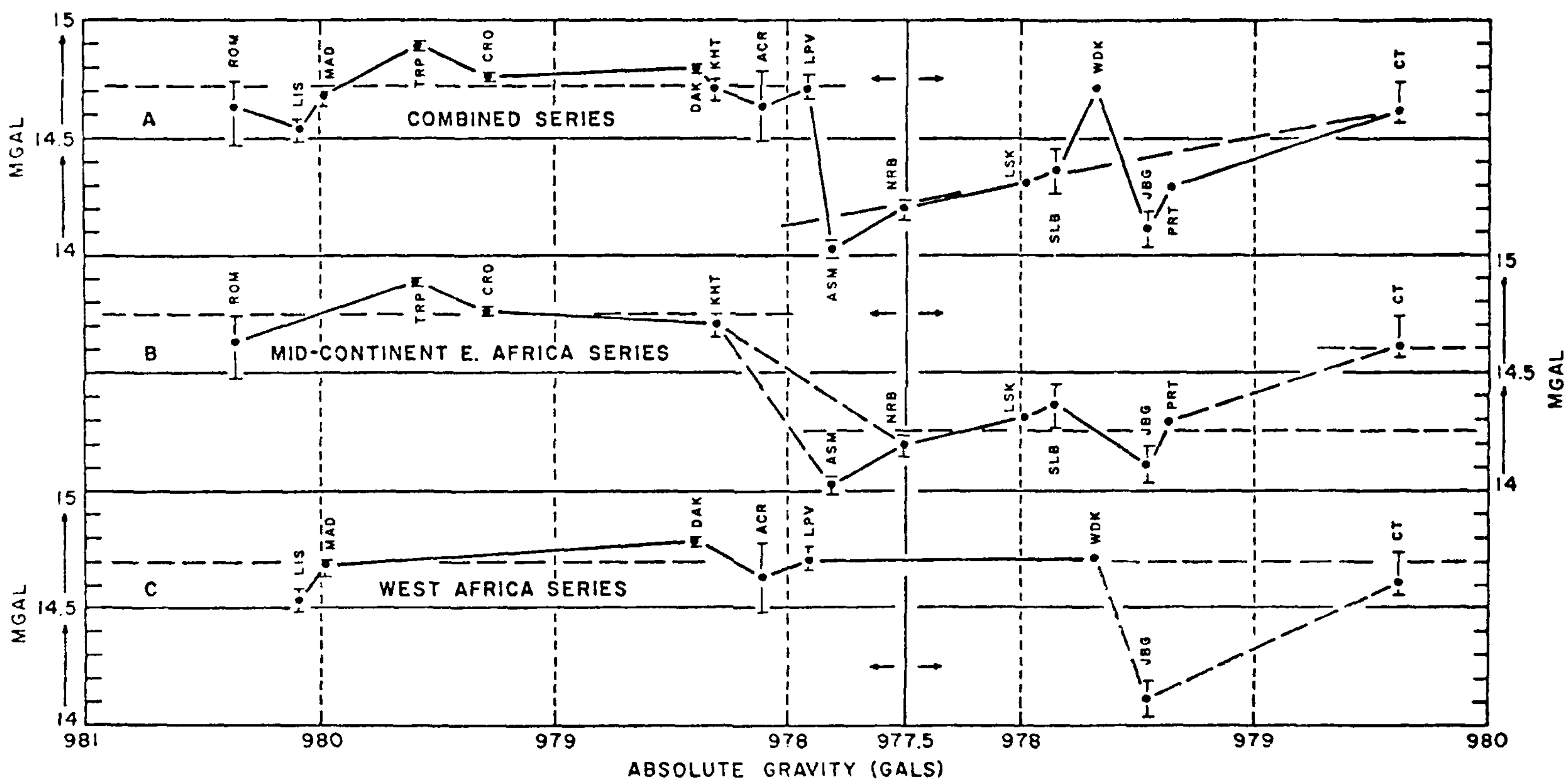


Fig. 11. Difference between Woollard and Rose (1963) and IGSN 71 gravity values at pendulum sites in Africa. A - Combined data; B - Mid Continent (East Africa) Series; C - West Africa Series.

a function of absolute gravity. In order to have continuity with the data for Europe the values for the pendulum sites at Rome, Madrid and Lisbon are included. As the minimum gravity value represented occurs about half-way down the African continent, the absolute gravity scale is centered on a minimum value of 977.5 gals, which corresponds to Nairobi, with values increasing North and South from this point. This is particularly desirable in this case, for as seen from Figure 11 there is a marked offset in values in the equatorial region.

On an overall basis the combined data shown in section A suggests there are two patterns in the differences, which are offset from each other near the Equator. To the north the differences in values indicate the overall gravity standard defined by the Woollard and Rose values is in good agreement with that defined by the IGSN 71 values. A datum correction of -14.73 mgal would have only two values (Lisbon and Tripoli) differing by more than 0.1 mgal from the IGSN 71 values. To the south, but actually starting with the low gravity value for Asmara, Ethiopia, there is a 0.65 mgal negative offset in values and a pronounced slope of about 0.17 mgal per 1000 mgal associated with values southward to Capetown. It would also appear that the Woollard and Rose values are sub-standard at both Windhoek and Johannesburg. If the mid-continent series starting from Rome and passing through Khartoum and Nairobi (Section B) is considered separately, it is seen that the above pattern is probably related to poor gravity connections in opposite sign between Khartoum and Nairobi and between Johannesburg and Capetown, and that the apparent resulting slope defined is fortuitously reinforced by a poor gravity connection between Khartoum and Asmara, Ethiopia. The reality of this interpretation of the results indicated for the mid-continent East African series of Woollard and Rose values is indicated by the data for the West African series. This series (Section C) indicates that all values from Madrid through to Capetown except that for Johannesburg, but including Windhoek, define a gravity standard that is in agreement with the IGSN 71 standard. As the datum offset indicated (+14.70 mgal) is much the same as that for the northern sector of the mid-continent East Africa series (14.75 mgal), and since the Capetown value would only show a departure of about 0.1 mgal from this datum, there is every reason to believe that the Woollard and Rose values in East Africa incorporate two tares in the same sign (the Khartoum to Asmara and Khartoum to Nairobi connections) and one tare in opposite sign but similar magnitude (the Johannesburg to Capetown connection). On this basis the sector embracing the Asmara, Nairobi, Lusaka, Salisbury, Johannesburg and Pretoria values involves no difference in gravity standard from the other sectors or that of the IGSN 71 values but has a different datum offset of 14.2 mgal. If the Asmara value is disregarded in this context since it is related to the northern half of the continent rather than the southern half involving all the other values, the datum correction would be 14.25 mgal for the Nairobi-Pretoria sector. Asmara would then stand alone as an isolated poor value and Capetown would fit in with the West coast series.

COMPARISON OF WOOLLARD AND ROSE GRAVIMETER VALUES AND IGSN 71 VALUES AT PENDULUM SITES IN THE PACIFIC-AUSTRALIAN AREA

In Table 18 the Woollard and Rose (1963) gravimeter values at pendulum sites in the Pacific-Australian region are compared with the IGSN 71 and DMA-AC adjusted gravity values. As the differences in values

Table 18

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values at Pendulum sites and their Excenters

Pacific-Australian Series

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
HAWAII						
GW 55	Honolulu, Bishop Mus.	978.9530	"B" .93835	+14.65	.93836	+14.64
Pend	Univ. Inst. Geophys.	978.9593	"A" .94490	+14.40		
WA 443	Hickam AFB	978.9337	"J" .91914	+14.56		
WA 444	Old Int'l. AP	978.9325	"S" .91810	+14.40		
	New Int'l. AP	978.9335	"Q" .91893	+14.57		
	Inter Is. AP	978.9330	"R" .91843	+14.57		
JAPAN						
GW 103	Sapporo, Hokkaido	980.4406	"B" .42735	+13.25		
WA 2030	Chitose AP	980.4405	"J" .42734	+13.16		
GW 57	Tokyo Univ. ERI	979.8016	"A" .78722	+14.38		
WA 2037	Hanenda AP	979.7736	"L" .75916	+14.44		
Pend Base	Kyoto Univ.	979.7216	"A" .70727	+14.33	.70729	+14.31
GW 100	Kadena, Okinawa	979.1265	"A" .11222	+14.28		
WA 2057	Kadena MATS	979.1343	"J" .11992	+14.38		
PHILIPPINES						
GW 58	Manila, Clark AFB	978.3969	"A" .38230	+14.60		
WA 2061	Clark MATS	978.3965	"J" .38183	+14.67		
WA 2062	Manila Int'l. AP	978.3767	"K" .36192	+14.78		

Table 18 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
HONG KONG						
GW 101	US Consulate	978.7677	"A" .75231	+15.39		
WA 2008	Kai-Tak AP	978.7730	"J" .75766	+15.34		
VIETNAM						
Lejay Pend.	Saigon	978.2285				
WA 2081	Tan San Nhut AP	978.2300	"J" .21509	+14.91	.21509	+14.91
SINGAPORE						
GW 102	Univ. Malaya	978.0815	"A" .06668	+14.82	.06668	+14.82
Pend. Base	Raffles Mus.	978.0809	"B" .06604	+14.86		
WA 2071	Changi Crk. RAFB	978.0801	"E" .06521	+14.89		
WA 2072	Kallang AP	978.0817	"J" .06681	+14.89		
WA 2073	Paya Lebar AP	978.0804	"L" .06561	+14.79		
AUSTRALIA NORTHERN TERRITORY						
GW 88	Darwin (BMR Bldg.)	978.3140	"A" .29955	+14.45	.29955	+14.45
WA 3058	RAF Officers Club	978.3164	"B" .30192	+14.48		
WA 3014	Airport	978.3154	"J" .30093	+14.47		
WA 3013	Daly Waters BMRP	978.3892			.37487	+14.33

Table 18 (cont.)

		(1) Woollard and Rose	(2) IGSN 71		1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
QUEENSLAND							
GW 87	Cairns	978.5006	"A"	.48624	+14.36		
GW 86	Townsville RAF	978.6247	"B"	.61043	+14.27		
WA 3043	Airport	978.6240	"C"	.60966	+14.34	.60969	+14.31
GW 85	Brisbane Univ.	979.1695	"B"	.15516	+14.34		
GW 85A	Seismic vault	979.1701	"A"	.15593	+14.17		
WA 3004	Eagle Farm AP	979.1599	"J"	.14557	+14.33		
WA 3067	Archer AP	979.1683	"K"	.15411	+14.19		
BMR P	Rockhampton Jail	978.8707	"A"	.85606	+14.64	.85606	+14.64
WA 3038	Airport	978.8738	"J"	.85935	+14.45		
WA 3027	Maryborough BMR Pend.	979.0219	"A"	.00732	+14.58		
NEW SOUTH WALES							
GW 84	Sydney (N.S.L.)	979.6863	"A"	.67186	+14.44	.67185	+14.45
WA 3043	Kingsford-Smith AP	979.6993	"J"	.68480	+14.50		
WA 3041	Rose Bay AP	979.6965	"L"	.68198	+14.52		
VICTORIA							
GW 38	Melbourne BMR	979.9797	"A"	.96518	+14.52	.96516	+14.54
WA 3028	Essendon AP	979.9628	"J"	.94821	+14.59		
[illegible] Pend.	Kallista Forest Ranger Sta.	979.9100	"S"	.89538	+14.62		

Table 18 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
SOUTH AUSTRALIA						
BMR Pend.	Adelaide Univ.	979.7243			.70920	+15.10
WESTERN AUSTRALIA						
BMR P	Perth Univ.	979.3958	"A" .38086	+14.94	.38066	+15.14
WA 3035	Airport	979.4011	"K" .38632	+14.78		
WA 3015	Derby BMR Pend.	978.5207			.50569	+15.01
WA 3036	Port Hedland	978.6466			.63150	+15.10
NEW ZEALAND NORTH ISLAND						
GW 81	Wellington (L. Hutt)	980.2934	"C" .27909	+14.31		
Pend Base	Wellington DSIR	980.2656	"A" .25100	+14.60	.25099	+14.61
WA 3058	Rongotai AP	980.3064	"K" .29201	+14.39		
DSIR	Auckland WM Mus.	979.9487	"B" .93411	+14.59		
WA 3047	Whenuapai AP	979.9408	"C" .92604	+14.76		
NEW ZEALAND SOUTH ISLAND						
GW 79	Christchurch	980.5089	"A" .49429	+14.61	.49429	+14.61
WA 3103	Int'L Airport	980.4962	"L" .48159	+14.61		
WA 3049	Harewood AP	980.4962	"K" .48147	+14.73		
GW 89	Dunedin, Otago Univ.	980.7424	"A" .72753	+14.87	.72751	+14.89
WA 3051	Taieri Airport	980.7366	"C" .72175	+14.85		

Table 18 (cont.)

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
ANTARCTICA						
GW 82	McMurdo	982.9919	"A" .97683	+15.07	.97683	+15.07
WA 9013	Scott Base	982.9883	"L" .97318	+15.12		
GW 119	Mirny	982.4052			.39059	+14.61
GW 120	Mawson	982.4818			.46719	+14.61

for Sapporo, Japan and Hong Kong differ by more than 0.5 mgals from the mean of the differences for all of the other sites, they are clearly anomalous and are rejected as having any value in evaluating the gravity standard represented in the Woollard and Rose values.

In Figure 12 the differences between the Woollard and Rose values relative to the IGSN 71 and DMA-AC values are plotted as a function of absolute gravity. The value at San Francisco is included to provide continuity from the North American series of gravity standardization values through Hawaii to Tokyo. As the measurements in western Australia indicate an offset in datum from those in eastern Australia they are shown as a separate segment of the plot. As the minimum gravity value occurs at Singapore in the middle of the series, the absolute gravity scale is centered on 978 gals.

On an overall basis a long wave length oscillation in values is indicated between Tokyo and Dunedin, New Zealand. However, this is probably related to compensating tares of near equal magnitude and opposite sign between Hawaii and Manila and between Singapore and Darwin, Australia with another tare between Christchurch and Dunedin, New Zealand. On this basis no difference in gravity standard is indicated for the Woollard and Rose values relative to that of the IGSN 71 values. The apparent datum correction is -14.45 mgal except for the Manila, Saigon, Singapore segment which would have a datum correction of -14.8 mgal. All values with few exceptions would be within ± 0.15 mgal of these datum corrections.

That there is a datum offset for the western Australian series due to an apparent tare in the Woollard and Rose values between Adelaide

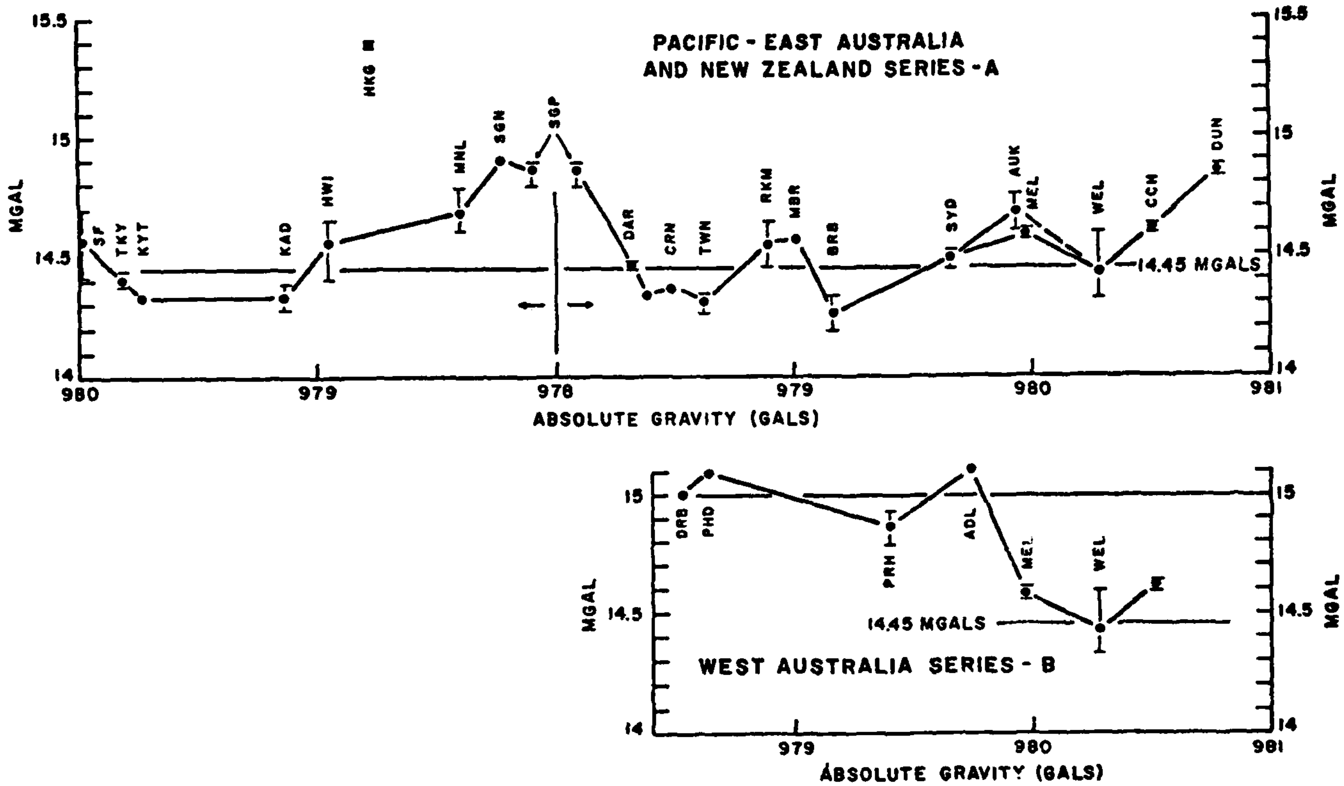


Fig. 12

Fig. 12. Difference between Woollard and Rose (1963) and IGSN 71 gravity values at pendulum sites in the Pacific- Australian area. A- Pacific Eastern Australia and New Zealand series; B- Western Australia series.

and Melbourne is brought out by the plot for these values and their relation to those in Eastern Australia and New Zealand. The datum correction indicated for this segment is approximately -15.0 mgal.

There is also a slight datum offset of about 0.05 mgal indicated in the Woollard and Rose connection between Australia and New Zealand, but this is inconsequential in comparison to that indicated between Christchurch and Dunedin, the end point for the series.

Although Antarctica is a logical extension of the western Pacific series and values for both McMurdo Sound and Mawson are included in Table 18, these points are too remote from other land masses to be considered as part of the western Pacific gravity standardization series. As seen from Table 18 the difference between the Woollard and Rose and the IGSN values at McMurdo and Scott Base average 15.1 $\pm$0.03 mgal and the single comparison at Mawson indicates a difference of 14.61 mgal. As will be discussed later, it is not possible to really evaluate the Woollard and Rose values in Antarctica since so few measurements have been made by other groups in this area at the same sites.

COMPARISON OF WOOLLARD AND ROSE GRAVIMETER VALUES AND IGSN 71 VALUES AT PENDULUM SITES IN INDIA AND ICELAND

Table 19 presents the differences between the Woollard and Rose (1963) gravimeter values and IGSN 71 and DMA-AC adjusted values at pendulum sites in India and Iceland. Because the range of gravity values at pendulum sites in India is limited, and because the datum correction indicated between sites in northern and southern India and Ceylon differ significantly, no plot of values is given. The average values from North to South are as follows:

Table 19

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values at Pendulum sites and their Excenters

India and Iceland

		(1) Woollard and Rose	(2) IGSN 71	1-2 Diff. (mgal)	(3) IGSN 71 DMA AC	1-3 Diff. (mgal)
INDIA						
GW 59	New Delhi	979.1363	"A" .12155	+14.75		
WA 2019	Palam AP	979.1341	"J" .11938	+14.72		
WA 2020	Willingdon AP	979.1379	"K" .12316	+14.74		
Natl.Gr. Base	Dehra Dun	979.0636	"A" .04909	+14.51	.04908	+14.52
SI Pend.	Bangaladore	978.0294	"A" .01389	+15.51	.01389	+15.51
WA 2011	Bangaladore AP	978.0387	"J" .02314	+15.56		
SI Pend.	Madras Metr. Cntr.	978.2818	"A" .26655	+15.25	.26655	+15.25
WA 2018	St. Thomas Mt. AP	978.2804	"J" .26516	+15.24		
CEYLON						
SI Pend	Colombo Metr. Obs.	978.1328	"B" .11724	+15.56		
Mejnesz Pend.	French Consulate	978.1403	"C" .12454	+15.76	.12454	+15.76
WA 2004	Ratmalana AP	978.1323	"J" .11690	+15.40		
ICELAND						
IGM Base	Reykjavik Univ.	982.2800	"A" .26496	+15.04		
WH 1035	Long Pier	982.2813	"J" .26634	+14.96		
WA 7006	Keflavik AP	982.2744	"K" .25943	+14.97		
WA 7007	Reykjavik AP	982.2784	"L" .26333	+15.07		

Dehra Dun	+14.51 mgal	(1 comparative value)
New Delhi	+14.74 ±0.02 mgal	(3 comparative values)
Bangladore	+15.54 ±0.03 mgal	(2 comparative values)
Madras	+15.25 ±0.01 mgal	(2 comparative values)
Colombo, Ceylon	+15.57 ±0.17 mgal	(3 comparative values)

These comparisons could indicate a difference in gravity standard since in general the absolute gravity values decrease from North to South. However the spread in the differences (14.51 to 15.57 mgal) appears excessive for the 1000-mgal change involved to be related to instrument calibration. It is therefore probable that the data for Colombo, Madras and Bangladore are offset by a datum shift (tare) from that for New Delhi and Dehra Dun.

As only one pendulum site and its excenters are represented by the comparative data for Iceland, the datum difference represented relative to the IGSN 71 values has significance. This is 15.01 ±0.04 mgal and comparable to that noted for Aberdeen and Edinburgh, Scotland; 14.98 and 14.87 mgal respectively.

CONCLUSIONS REGARDING THE GRAVITY STANDARD REPRESENTED IN THE WOOLLARD AND ROSE (1963) GRAVIMETER VALUES RELATIVE TO THE IGSN 71 GRAVITY STANDARD

On an overall basis the Woollard and Rose (1963) gravimeter values at pendulum sites and their excenters for the 11 gravity standardization ranges examined indicate no discernable difference in gravity standard from that incorporated in the IGSN 71 values. In the one instance in which a systematic departure in values was noted, the Andean series in South America, it would appear this departure is related to a difference in calibration of the gravimeters used. This conclusion is based on the magnitude of the difference in standard indicated (0.2 mgal) per 1000 mgals change) and the fact that the departures in values from the standard defined does not exceed 0.1 mgal except at one site. Although the best series of measurements were clearly carried out in North America in that the spread in values on average is less than ± 0.1 mgal in defining a datum difference relative to the IGSN 71 values, there are on the whole surprisingly small shifts in datum in going from one continent range series to another. However, five of the series of observations appear to incorporate internal datum shifts (tares)as well as a few poor values that do not fit in with the rest of the values. Sites falling into this latter category appear to be Sapporo, Japan; Hong Kong; Asmara, Ethiopia and Dunedin, New Zealand. The series that appear to be affected by internal datum shifts and their locations are: (1) the South America Atlantic coast series with a negative datum shift of about 0.3 mgal between Belem and Rio de Janeiro, Brazil followed by a positive datum shift of about 0.5 mgal between Buenos Aires and Mar del Plata, Argentina; (2) the Central Africa series with a negative datum offset of about 0.5 mgal between Khartoum, Sudan and Nairobi, Kenya followed by a positive datum shift of about 0.4 mgal between Johannesburg and Capetown; (3) the Pacific-Australia series with a positive datum shift of about 0.35 mgal between Hawaii and Manila followed by a negative datum shift of the same magnitude between Singapore and Darwin, Australia; (4) the Western Australia series which has a positive datum shift of about 0.5 mgal between Melbourne and Adelaide; (5) the Indian series with a positive datum shift of about 0.7 mgal between New Delhi and Bangladore.

In terms of datum shifts between the various series and the average departures in values from the datum defined the relations are as brought out in Table 20. The average datum shift defined, and omitting the Andean series which is apparently biased by an instrument calibration problem, is 14.78 mgal with an average deviation from this value of ±0.24 mgal. The extremes being 14.45 mgal (the Pacific-Australia series) and 15.45 mgal (the southern India values). The distribution pattern is slightly skewed with 7 values being less than the mean average value and 5 values being greater than the mean by 0.1 mgal or more. The average spread in values defining the individual datum corrections is ±0.08 mgal with a spread in values ranging from ±0.04 mgal to ±0.13 mgal. Considering the uncertainty of 0.3 mgal in the Woollard and Rose (1963) values and the 0.1 mgal uncertainty in the IGSN 71 values the degree of correlation in the values as regards the gravity standard defined and the small average deviation of ±0.25 mgal from the mean in defining the datum difference, the results are surprisingly good.

COMPARISON OF WOOLLARD AND ROSE (1963) GRAVIMETER VALUES AND IGSN 71 VALUES ON AN AREAL BASIS

The value in having comparisons of the Woollard and Rose (1963) gravity values with IGSN 71 values at sites other than pendulum bases lies in their defining the datum correction for the Woollard and Rose values on an areal basis. The data that will be considered will include all values (pendulum sites, airport sites and harbor sites) related to areas. By examining all the data, it should be possible to resolve some of the problems regarding possible calibration variations suggested in examining the data at pendulum sites. With a succession of instruments being modified and improved plus improvements in calibration and some

Table 20

Datum difference for Woollard and Rose (1963) values relative to IGSN 71 values on the principal gravity standardization ranges.

RANGE

North America

West Coast Series (Pt. Barrow, Alaska-Monterrey, Mexico)

Gravity range: 3900 mgal . Sites: 9, Datum corr. +14.55 mgal . Average Diff. ±0.07 mgal.

Rocky Mt. Front Series (Pt. Barrow, Alaska-Monterrey, Mexico)

Gravity range: 3900 mgals. Sites: 14, Datum Corr. +14.55 mgal . Average Diff. ±0.08 mgal.

Mid Continent Series (Madison, Wisconsin- Monterrey, Mexico)

Gravity range: 1600 mgal . Sites: 6, Datum corr. +14.60 mgal . Average Diff. ±0.07 mgal.

East Coast Series (Ottawa, Ontario-Key West, Florida)

Gravity range: 1700 mgal . Sites: 7, Datum corr. +14.57 mgal . Average Diff. ±0.04 mgal.

South America

Andean Series (Panama - Punta Arenas, Chile)

Gravity range: 4100 mgal . Sites 8, Datum corr. variable

Datum corr: X=15 + [0.02(Woollard and Rose value-978.5)]

Average Diff. ±0.10 mgal.

Atlantic Coast Series (Panama - Ushuaia, Argentina)

Gravity range: 3500 mgal . Sites: 9, Datum corr. variable

Panama, Caracas, Belem +15.0 mgal . Avg. Diff ±0.07 mgal.

Rio de Janeiro, Cordoba, Buenos Aires +14.8 mgal ,

average diff. ±0.03 mgal.

Table 20 (cont)

Mar del Plata, Rio Gallegos, Ushuaia +15.3 mgal , average diff. ±0.04 mgal.

Europe

Overall Series (Hammerfest, Norway - Cairo, Egypt)

Gravity range: 3500 mgal . Sites: 22, Datum corr. +14.75 mgals, Average Diff. ±0.12 mgal.

Pacific - Australia Area

Principal Series (Tokyo, Japan - Christchurch, New Zealand)

Gravity range: 2800 mgal , Sites: 18, Datum corr. variable

San Francisco, Hawaii, Tokyo, Kyoto, Kaneda +14.45 mgal Average Diff. ±0.10 mgal.

Manila, Saigon, Singapore +14.8 mgal , Avg. Diff. ± 0.1 mgal.

Darwin, Cairns, Townsville, Brisbane, Rockhamption, Maryborough, Sydney, Melbourne, Auckland, Wellington, Christchurch: +14.45 mgal , Avg. Diff. ±0.10 mgal.

West Australia Series (Adelaide-Derby)

Gravity Range: 2000 mgal , Sites: 4, Datum Corr. +15.0 mgal . Average Diff. ±0.10 mgal.

Indian Series

Gravity Range: 1000 mgal , Sites: 5, Datum Corr. variable

Dehra Dun, New Delhi +14.6[illegible] mgal . Avg. Diff. ±0.11 mgal.

Bangladore, Madras, Colombo +15.45 mgal , Average Diff. ±0.13 mgal.

areas only being visited once, some calibration problems as brought out in South America were certain to be present. In the following tables the IGSN 71 values marked with an asterisk are those given by DMA-AC. Otherwise the values are those of Morelli et al. (1974). Sites shown with a question mark indicate that the values may not have been taken at the same site at that location. The site designation numbers are those of Woollard and Rose (1963), and the values are segregated by country or state and arranged alphabetically both as regards state name and town name. This is the same arrangement as used for the DMA-AC IGSN 71 values which is the principal source for most of the comparitive values, as well as the system that was used by Woollard and Rose. Each continent is taken up separately starting with North America.

America.

NORTH AMERICAN AREA: COMPARISONS IN ALASKA

Table 21 presents the comparative data for Alaska. There are 59 comparative values with only 6 queried as to not being the same sites. Although there are undoubtably other sites where the values are not for the same location, these can not be positively identified. In general, if the differences in values relative to the mean did not exceed twice the ±0.3 mgal reliability claimed for the Woollard and Rose values, the data were accepted as being for the same site. A few values exceeding these limits were included as it did appear in these cases that the same sites were involved.

As seen from the distribution plot (Figure 13A) the spread in the differences in the Woollard and Rose values relative to the IGSN 71 values is large (13.6 mgal to 15.3 mgal to the nearest 0.1 mgal). This

Table 21

Comparison of Woollard and Rose (1963)

Gravimeter Values with IGSN 71 Values

on an Areal Basis in Alaska

		Woollard and Rose	IGSN 71	Diff.	
WA 321	Adak 'J'	981.4420	.427 64	14.36	
WA 322	Allaket	982.3583	.344 05*	14.25	
WA 323	Anchorage	981.9204	.905 86*	14.54	
			.905 82*	14.58	
USC Pend	Anchorage 'A'	981.9400	.925 19	14.81	
WA 474	Elmendorf AFB 'J'	981.9382	.923 56	14.64	
WA 324	Annette Is.	981.5274	.513 28*	14.12	
WA 325	Barter Is.'J'	982.5954	.581 56	13.84	
			.581 55*	13.85	
WA 327	Beaver	982.3315	.316 40*	15.10	
WA 329	Bettles	982.3842	.369 45*	14.75	
WA 331	Cape Lisburne	982.5304	.516 59*	13.81	
WA 332	Cape Newenham	981.8247	.809 97*	14.73	
WA 337	Chitina	981.9492	.929 47*	19.73	Site?
WA 338	Circle	982.3049	.290 09*	14.81	
WA 339	Cordova	981.9579	.934 09*	14.81	
WA 340	Demarcation Pt.	982.5672	.552 93*	14.27	
WA 341	Dillingham	981.8658	.854 74*	11.06	Site?
WA 342	Dutch Harbor	981.5530	.538 58*	14.42	
GW 6	Fairbanks "A"	982.2462	.231 71	14.49	
			.231 70*	14.50	
GW 27	Fairbanks "B"	982.2444	.229 91	14.49	
Abs	Fairbanks "E"	982.2495	.235 00	14.50	
WA 279	Fairbanks "J"	982.2464	.231 97	14.43	
WA 349	Flat	982.0936	.078 91*	14.69	
WA 351	Fort Yukon	982.3580	.343 40*	14.60	
WA 355	Gulkana	981.9314	.916 95*	14.45	
WA 357	Homer	981.8824	.868 49*	13.91	
WA 358	Hughes	982.3341	.319 45*	14.65	

Table 21

Alaska (cont.)

		Woollard and Rose	IGSN 71	Diff.	
WA 360	Huslia	982.3213	.307 90*	13.40	Site?
WA 361	Iliamna	981.9030	.888 39*	14.61	
WA 363	Juneau	981.7680	.753 64*	14.36	
WA 364	Kenai	981.8378	.822 78*	15.02	
WA 365	King Salmon	981.8426	.827 99*	14.61	
WA 368	Kotzebue	982.4141	.339 73*	14.37	
WA 369	Koyuk	982.2929	.278 51*	14.39	
WA 370	Koyukuk	982.2801	.266 34*	13.76	
WA 372	Livengood	982.2725	.258 23*	14.27	
WA 375	McGrath	982.1284	.113 59*	14.81	
WA 377	Munchumina	982.1545	.139 98*	14.52	
WA 380	Nome	982.2749	.259 20*	15.70	Site?
WA 382	Palmer	981.9816	.967 99*	13.61	
GW 105	Point Barrow "A"	982.6996	.685 18	14.42	
			.685 17*	14.43	
WA 280	Point Barrow "K"	982.6998	.685 21	14.59	
WA 385	Ruby	982.2376	.252 55*	15.05	
WA 387	Shemya	981.5088	.492 08*	16.72	Site?
WA 388	Skagway	981.7736	.758 80*	14.80	
WA 390	Stevens Village	982.3244	.309 06*	15.34	
WA 393	Tanana	982.2782	.263 70*	14.50	
WA 395	Teller	982.3119	.297 15*	14.75	
WA 396	Tin City	982.3141	.299 63*	14.47	
WA 281	Umiat	982.5444	.529 65*	14.75	
WA 397	Umnak Is.	981.5176	.502 73*	14.87	
WA 398	Unalakleet	982.2178	.202 83*	14.97	
WA 404	Yakataga	981.9037	.891 54*	12.16	Site?
WA 405	Yakutat	981.8371	.822 49*	14.61	

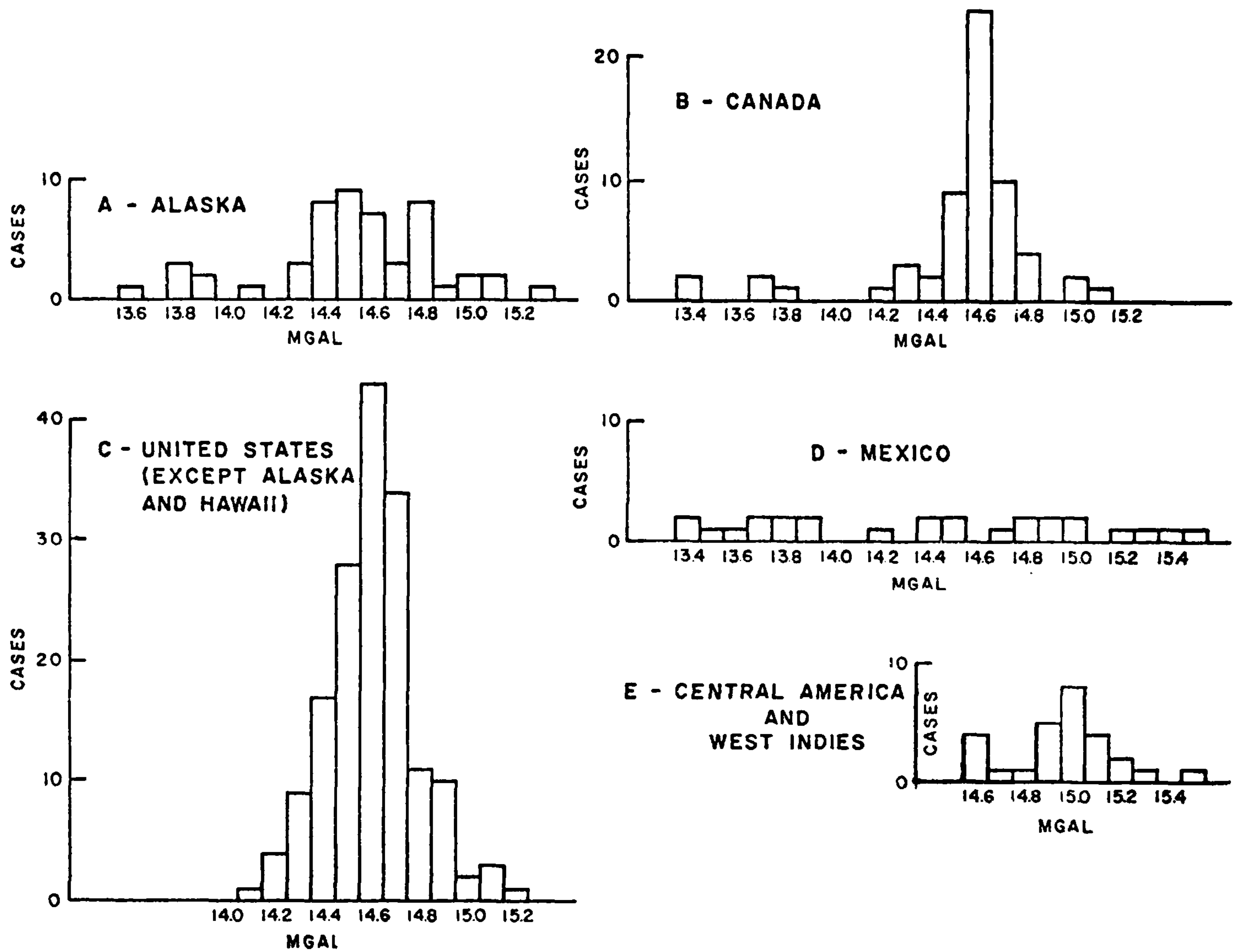


Fig. 13

Fig. 13. Distribution plots of differences in Woollard and Rose gravimeter values and IGSN 71 values on an areal basis in North America. A-Alaska; B-Canada; C-United States; D-Mexico; E-Central America and the West Indies.

could reflect the pressence of tares in certain portions of the data, or also differences in calibration standard of the instruments used. However, 73 percent of the values representing 38 of the 52 unqueried sites fall within the bounds of 14.3 mgal and 14.8 mgal and define an average median value of 14.56 mgal. The results of the comparisons are better than might be anticipated considering the many severe problems encountered. That there was a difference in calibration standard as well as tares in the data will be brought out when the results are summarized for all four areas comprising the North American group.

COMPARISONS IN CANADA

In Table 22 the comparative data for the Woollard and Rose (1963) values relative to the IGSN 71 values are given for Canada on a province by province basis. Only 2 of the 59 sites are queried and only one group of values (differences of 13.4 to 13.8 mgal) appear to reflect a tare or tares. In regard to these anomalous values, four of these values are for observations at Resolute Bay and Eureka in the Northwest Territory which probably incorporated a tare when the propeller back wash of a plane sent both the instrument and observer tumbling across the ice. As seen from the distribution plot (Figure 13B), the bulk of the data define a normal distribution with a median value of 14.6 mgal for the difference between Woollard and Rose (1963) and the IGSN 71 values. Seventy three percent of the values fell within the bounds of ±0.1 mgal from the mean.

Table 22

Comparison of Woollard and Rose Gravimeter Values

and IGSN 71 Values on an Areal Basis in Canada

		Woollard and Rose	IGSN 71	Diff.
ALBERTA				
GW 32	Calgary "A"	980.8281	813 55	14.55
WA 180	Calgary "J"	980.8288	814 25	14.55
GW 25	Edmonton "B"	981.1678	153 16	14.64
			153 09*	14.71
GW 5	Edmonton "C"	981.1672	152 79	14.41
WA 181	Edmonton "K"	981.1729	158 38	14.52
WA 282	RCAF NAMAO "M"	981.1803	165 84	14.46
Camb	Grande Prairie "A"	981.3180	303 22	14.78
			303 20*	14.80
GW 10	Grande Prairie "B"	981.3175	302 85	14.65
WA 183	Grande Prairie "J"	981.3158	300 99	14.81
GW 33	Lethbridge "A"	981.7589	744 62	14.28
			744 61*	14.29
GW 12	Lethbridge "C"	981.7584	744 18	14.22
WA 184	Lethbridge "J"	981.7538	739 15	14.65
BRITISH COLOMBIA				
Camb	Fort Nelson "A"	981.6828	668 17*	14.63
WA 182	Fort Nelson "J"	981.6929	678 39	14.51
GW 27	Fort St. John "A"	981.4059	391 21	14.69
WA 284	Fort St. John "J"	981.4055	390 78	14.72
			390 79*	14.71
WA 285	Liard River	981.7041	689 47*	14.63
WA 286	Prince George	981.1772	162 14*	15.06
WA 288	Sikanni Chief	981.3941	379 46*	14.64
Dom Obs	Vancouver "A"	980.9352	920 68	14.52
			920 68*	14.52
WA 186	Vancouver "J"	980.9299	915 41	14.49

Table 22 (cont.)

Canada (cont.)

		Woollard and Rose	IGSN 71	Diff.	
	LABRADOR				
WA 291	Goose Bay "J"	981.3078	292 81	14.99	
	"K"		293 24	14.56	
	MANITOBA				
WA 292	Churchill	981.7675	752 87*	14.63	
WA 80	Winnipeg "J"	980.9924	977 56	14.84	
	NEWFOUNDLAND				
WA 294	Argentia	980.8539	840 15*	13.75	site?
WA 297	St. Johns	980.8369	822 25*	14.65	
WA 298	Stephenville	980.9318	916 77*	15.03	
	NORTHWEST TERRITORY				
WA 301	Aklavik	982.4902	475 59*	14.61	
WA 302	Cape Parry	982.6220	607 40*	14.60	
	Cornwallis Is.				
WA 303	Resolute Bay	982.8624	848 74	13.66	
			848 73*	13.67	
	Ellesmere Land				
WA 304	Alert	983.1417	117 96*	23.74	site?
WA 305	Eureka	983.0275	014 09	13.41	
			014 06*	13.44	
	Ellef Rignes Is.				
WA 306	Isachsen	983.0597	045 10*	14.60	
	Prince Patrick Is.				
WA 307	Mould Bay	982.9333	.918 70*	14.60	
WA 308	Yellowknife	982.0245	.009 88*	14.62	
	Victoria Island				
WA 309	Cambridge Bay	982.5182	.503 59*	14.61	
	ONTARIO				
Dom Obs	Ottawa "A"	980.6208	606 14	14.66	
GW 53	Ottawa "B"	980.6217	607 10	14.60	
			607 07*	14.63	
WA 310	Ottawa "L"	980.6187	604 14	14.56	
WA 79	Toronto	980.4298	415 09	14.71	
			415 09*	14.71	

Table 22 (cont.)

Canada (cont.)

		Woollard and Rose	IGSN 71	Diff.
QUEBEC				
WA 77	Montreal "N"	980.6437	629 24	14.46
WA 185	Quebec	980.7405	725 92*	14.58
YUKON				
WA 311	Burwash	981.7543	739 67*	14.63
WA 312	Dawson	982.5223	507 69*	14.61
WA 313	Shingle Point	982.5223	507 69*	14.61
WA 314	Stokes Point	982.5702	555 59*	14.61
WA 315	Teslin Lake	981.7270	712 37*	14.63
Dom Obs	Watson Lake "A"	981.7150	700 39	14.61
WA 476	Watson Lake "J"	981.7143	699 98	14.32
GW 26	Whitehorse "B"	981.7486	734 25	14.35
WA 188	Whitehorse "J"	981.7487	734 25	14.45

COMPARISONS IN THE UNITED STATES

In Table 23 the comparative data for the Woollard and Rose values relative to the IGSN 71 values are listed for the United States on a state by state basis (omitting Alaska and Hawaii). The distribution plot for the 143 values (Figure13C) defines a median value of 14.6 mgal with 63 percent of the values falling within the bounds of ±0.1 mgal from the mean and 79 percent of the values falling within ±0.2 mgal from the mean.

COMPARISONS IN MEXICO

The comparative data for the Woollard and Rose (1963) values relative to the IGSN 71 values is given in Table 24. There are 28 values for comparison, of which 3 are queried as to site location. That the Mexican data incorporate a number of tares is reflected by the wide spread in the differences (13.4 to 15.4 mgal) and as brought out in the distribution plot (Figure 13D) there are apparently four groupings of the data. One appears to be centered for differences in values at 13.65 mgal ; one at 14.4 mgal ; one at 14.9 mgal , and one at 15.35 mgal . There is no readily apparent explanation for these distributions other than that the Mexican observations were made over a series of years and incorporate some of the earliest observations with the bulk of the data represented having been obtained on road traverses using truck transport rather than plane transport, and as series of loops with long periods for closure.

COMPARISONS IN CENTRAL AMERICA AND THE WEST INDIES

Table 25 presents the comparative data for the Woollard and Rose (1963) values relative to the IGSN 71 values. Comparative data for 27 sites are listed. No sites are queried as all such sites (5) were eliminated in

Table 23

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values on an Areal basis in the United States

		Woollard and Rose	IGSN 71	Diff.
ALABAMA				
WA 82	Mobile	979.3396	324 69*	14.91
ARIZONA				
WA 194	Douglas	979.0576	042 90*	14.70
WA 195	Flagstaff	979.1427	128 35*	14.35
WA 196	Nogales	979.0701	055 24*	14.86
WA 2	Phoenix	979.4918	476 83*	14.97
WA 197	Prescott	979.2406	226 39*	14.21
WA 3	Tucson	979.2277	213 01*	14.69
WA 198	Winslow	979.2777	263 55*	14.15
ARKANSAS				
WA 4	Little Rock "J"	979.7245	709 40	15.10
CALIFORNIA			709 40*	15.10
WA 202	Fairfield	979.9898	975 38*	14.42
WA 83	Los Angeles	979.5946	580 00*	14.60
WA 207	Red Bluff	980.1046	090 06*	14.54
WA 85	San Diego "J"	979.5369	522 36	14.54
			522 38*	14.52
WA 453	San Diego "K"	979.5336	518 54	15.06
GW 54	San Francisco "A"	979.9867	972 13	14.57
			972 37*	14.33
WA 86	San Francisco "K"	979.9883	973 75	14.55
WA 87	San Francisco "J"	979.9885	973 81	14.69
COLORADO				
GW 39	Denver "B"	979.6117	597 10	14.60
X cntr	Denver "D"	979.6114	596 53	14.87
WA 89	Denver "J"	979.6333	618 97	14.33
WA 90	Denver "K"	979.6327	618 48	14.22
CONNECTICUT				
WU 8	New Haven	980.3163	301 50*	14.80

Table 23 (cont.)

United States (cont.)

		Woollard and Rose	IGSN 71	Diff.	
DISTRICT OF COLOMBIA					
US 337	Commerce Pier "A"	980.1188	.104 29	-14.51	
U337A	Commerce 14th St. "C"	980.1182	.103.63	-14.57	
GW 2	CIW Dept.Terr.Mag."D"	980.1006	.086 05	-14.55	
Old NBS	NBS Abs Conn Av. "E"	980.0995	.084 86	-14.64	
WA 493	Natl. Airport "K"	980.1089	.094 40	-14.50	
FLORIDA					
WA 484	Daytona Beach "J"	979.2771	.262 50	-14.60	
WA 217	Jacksonville "J"	979.3856	.370 97	-14.63	
GW 116	Key West "A"	978.9692	.954 46	-14.54	
WH 39	Key West NB "J"	978.9686	.954 07	-14.53	
GW 115	Miami Mar. Lab. "A"	979.0356	.020 95	-14.65	
WH 3	Miami Port "B"	979.0356	.020 96	-14.64	
WA 278	Miami Intl. AP "J"	979.0528	.038 29	-14.51	
WA 11	Miami EAL "L"	979.0543	.039 57	-14.73	
WA 13	Orlando AP "J"	979.2187	.204 09	-14.61	
WA 464	Orlando McCoy AFB "L"	979.2004	.185 84	-14.56	
WA 461	Pompano Beach "N"	979.0864	.071 58	-14.82	
WA 462	St. Augustine "O"	979.3418	.327 21	-14.59	
WA 16	Tampa "J"	979.2044	.189 59	-14.81	
			.189 53*	-14.87	
WA 460	Vero Beach "J"	979.1737	.159 04	-14.66	
WA 17	West Palm Beach "J"	979.1333	.118 70	-14.60	
GEORGIA					
	Atlanta, Emory U. "A"	979.5380	.523 57	-14.43	
WA 470	Atlanta AP "J"	979.5206	.506 31	-14.29	
WA 469	Atlanta AP "K"	979.5211	.506.90	-14.20	
WA 18	Brunswick "J"	979.4494	.434 74	-14.66	
WA 19	Columbus	979.5125	.507 31*	-15.19	Site?
WA 20	Macon	979.5321	.517 48*	-14.62	
WA 99	Savannah "J"	979.4977	.483 08	-14.62	
IDAHO					
WA 21	Boise "J"	980.2082	.193 64	-14.56	

Table 23 (cont.)

United States (cont.)

		Woollard and Rose	IGSN 71	Diff.	
ILLINOIS					
GW 23	Chicago "A"	980.2873	.272 62	-14.68	
WA 101	Midway "J"	980.2864	.271 79	-14.61	
WA 23	Springfield	980.0821	.067 43*	-14.67	
INDIANA					
WA 103	West Lafayette	980.1469	.132 40*	-14.50	
IOWA					
WA 220	Boone	980.3226	.307 59*	-15.01	
W 24	Cedar Rapids	980.2519	.237 35*	-14.55	
WA 221	Cleremont	980.3787	.363 93*	-14.77	
WA 222	Davenport	980.2521	.236 60*	-15.50	site?
WA 25	Des Moines	980.1984	.184 41*	-13.99	site?
WA 228	Sioux City "J"	980.3073	.292 98	-14.32	
KANSAS					
GW 52	Beloit	979.9981	.983 59*	-14.51	
WA 106	Wichita "J"	979.8408	.826 26	-14.54	
KENTUCKY					
WA 107	Lexington	979.8988	.884 12*	-14.68	
WA 26	Louisville "J"	979.9585	.943 67	-14.83	
LOUISIANA					
WA 108	Baton Rouge	979.3637	.349 01*	-14.69	
WA 230	Lake Charles	979.3324	.317 71*	-14.69	
WA 110	New Orleans "J"	979.3298	.314 94	-14.86	
MAINE					
WA 231	Augusta	980.5372	.522 54*	-14.66	
WA 457	Bangor "J"	980.5912	.576 45	-14.75	
WA 458	Caribou "J"	980.7322	.717 49	-14.71	
WA 232	Greenville	980.5895	.574 84*	-14.66	
MARYLAND					
WA 112	Baltimore "M"	980.1034	.088 67	-14.73	
MASSACHUSETTS					
WA 114	Boston "O"	980.4036	.389 24	-14.36	
WA 472	Hyannis	980.3400	.325 41*	-14.59	

Table 23 (cont.)

United States (cont.)

		Woollard and Rose	IGSN 71	Diff.	
GW 77A	Woods Hole BM	980.3271	.312 49*	-14.61	
MICHIGAN					
	Detroit				
WA 116	"K" Willow Run AP	980.3188	.304 08	-14.72	
WA 496	"L" Metropolitan AP	980.3190	.304 46	-14.54	
MINNESOTA					
WA 118	Minneapolis "K"	980.5950	.580 92	-14.08	Site?
MISSOURI					
WA 120	Kansas City "J"	979.9998	.985 46	-14.34	
WA 121	St. Louis "J"	980.0042	.989 52	-14.68	
MONTANA					
GW 25	Billings "A"	980.3710	.356 37	-14.63	
WA 122	Billings AP "K"	980.3717	.357 37	-14.33	
WA 123	Butte	980.1744	.159 88*	-14.52	
GW 34	Cutbank "B"	980.6085	.593 83	-14.67	
WA 242	Glendive	980.6371	.622 44*	-14.66	
GW 4	Great Falls "A"	980.5269	.512 30	-14.60	
WA 482	Great Falls "J"	980.5137	.499 11	-14.59	
WA 243	Malmstrom AFB "K"	980.5291	.514 52	-14.58	
WA 31	Helena	980.3778	.363 50*	-14.30	
WA 32	Kalispell	980.5818	.567 39*	-14.41	
WA 244	Miles City	980.5230	.508 55*	-14.45	
WA 127	Missoula	980.4440	.429 45*	-14.55	
WA 245	Stanford	980.4369	.422 55*	-14.35	
NEVADA					
WA 39	Ely	979.4946	.480 08*	-14.52	
WA 450	Indian Springs	979.5560	.541 16*	-14.84	Site?
WA 128	Las Vegas "J"	979.6049	.590 37	-14.53	
WA 40	Tonopah	979.4767	.462 25*	-14.45	
NEW JERSEY					
WA 248	Newark	980.2415	.226 89*	-14.61	
GW 78	Princeton "A"	980.1783	.163 73	-14.57	
GW 78A	Princeton Univ "B"	980.1776	.163 06	-14.54	

Table 23 (cont.)

United States (cont.)

		Woollard and Rose	IGSN 71	Diff.	
WA 42	McGuire AFB "J"	980.2128	.198 36	-14.44	
	NEW MEXICO				
WA 130	Albuquerque "K"	980.2081	.193 51	-14.59	
	NEW YORK				
	New York City				
WA 252	Idlewild "R"	980.2273	.212 59	-14.71	
WA 133	Kennedy "K"	980.2261	.211 35	-14.75	
WA 132	La Guardia "S"	980.2825	.267 77	-14.73	
WA 14	Navy Yard "Q"	980.2721	.257 36	-14.74	
WA 134	Syracuse "K"	980.3968	.382 08	-14.72	
	NORTH CAROLINA				
WA 44	Charlotte "J"	979.7283	.713 43	-14.87	site?
WA 46	New Bern	979.7286	.714 16*	-14.44	
	NORTH DAKOTA				
WA 49	Bismarck "J"	980.6274	.612 75	-14.65	
WA 50	Fargo "J"	980.7270	.712 66	-14.34	
WA 51	Jamestown	980.6540	.639 34*	-14.66	
WA 447	Pembina	980.9166	.902 48*	-14.12	site?
	OHIO				
WA 137	Cleveland	980.2322	.217 56*	-14.64	
WA 22	Columbus (Univ.) "C"	980.0961	.081 40	-14.70	
WA 138	Columbus "J"	980.0791	.064 21	-14.89	site?
	OKLAHOMA				
GW 52	Tulsa Univ.	979.7661	.751 46*	-14.64	
	OREGON				
WA 140	Eugene	980.5148	.500 23*	-14.57	
WA 55	Pendleton	980.5117	.496 76*	-14.94	
WA 142	Portland "J"	980.6483	.633 62	-14.68	
WA 56	Salem	980.5837	.569 03*	-14.67	
	PENNSYLVANIA				
WA 145	Pittsburgh "J"	980.0993	.084 46	-14.84	
	SOUTH CAROLINA				
GW 90	Charleston "A"	979.5509	.536 35	-14.55	

Table 23 (cont.)

United States (cont.)

		Woollard and Rose	IGSN 71	Diff.
WA 449	Charleston AP "J"	979.5667	.552 16	-14.54
WA 148	Charleston AP "K"	979.5668	.552 27	-14.53
WA 147	Charleston MATS	979.5675	.552 98	-14.52
WA 57	Florence "J"	979.6851	.670 34	-14.76
SOUTH DAKOTA				
WA 59	Aberden	980.5438	.529 19*	-14.61
U 1200	Huron (BM)	980.4530	.438 59*	-14.41
WA 262	Sioux Falls "J"	980.3616	.347 49	-14.11
WA 64	Spearfish	980.2521	.237 98*	-14.12
TENNESSEE				
WA 149	Chattanooga	979.6505	.635 82*	-14.68
TEXAS				
GW 50	Amarillo "A"	979.4235	.409 11	-14.39
WA 67	Amarillo AP "J"	979.4234	.408 87	-14.53
WA 263	Beaumont	979.3149	.300 21*	-14.69
WA 264	Childress	979.4881	.473 95*	-14.15
WA 266	Dalhart	979.4402	.425 51*	-14.69
WA 154	Dallas "J"	979.5131	.498 41	-14.69
GW 18	Houston "A"	979.2983	.283 72	-14.58
WA 159	Houston "J"	979.2932	.278 66	-14.64
GW 18-A	Houston "B"	979.2983	.283 72	-14.58
WA 160	Laredo "J"	979.0792	.064 61	-14.59
WA 68	Lubbock "J"	979.3228	.308 36	-14.44
GW 40	San Antonio "A"	979.1975	.182 73	-14.77
WA 162	San Antonio "J"	979.1976	.182 86	-14.74
WA 161	San Antonio "L"	979.1973	.182 57	-14.73
UTAH				
WA 209	Ogden, Hill AFB "J"	979.8005	.786 08	-14.42
WA 163	Salt Lake City "L"	979.8070	.782 44	-14.56
WA 164	Vernal	979.6686	.653 80*	-14.80
VERMONT				
WA 165	Burlington	980.5181	.503 73*	-14.37
VIRGINIA				
WA 73	Richmond "J"	979.9534	.938 66	-14.74

Table 23 (cont.)

United States (cont.)

		Woollard and Rose	IGSN 71	Diff	
WA 168	Roanoke	979.8076	.793 11	-14.49	
	WASHINGTON				
GW 104	Seattle "A"	980.7388	.724 34	-14.46	
WA 170	Seattle AP "K"	980.7765	.762 02	-14.48	
WA 173	Spokane "K"	980.6463	.631 78	-14.52	
	WEST VIRGINIA				
WA 174	Charleston	979.9259	.911 29*	-14.61	
WA 274	Huntington	979.9519	.937 65*	-13.85	site?
	WISCONSIN				
GW 3	Madison "A"	980.3689	.354 22	-14.68	
WA 76	Madison AP "J"	980.3725	.357 82	-14.68	
	WYOMING				
GW 37	Casper Pend.	979.9558	.941 33*	-14.47	
WA 177	Casper AP "J"	979.9562	.941 59	-14.61	
GW 38	Cheyenne "A"	979.7006	.686 18	-14.42	
GW 37	Cheyenne "B"	979.7008	.686 30	-14.50	
WA 178	Cheyenne AP "J"	979.7008	.686 23	-14.57	
WA 276	Douglas	979.9533	.938 62*	-14.68	
GW 36	Sheridan "A"	980.2264	.212 05	-14.35	
WA 179	Sheridan "J"	980.2265	.212 14	-14.36	

Table 24

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values on an Areal Basis in Mexico

		Woollard and Rose	IGSN 71	Diff.	
BAJA CALIFORNIA SUR					
WA 432	Santa Rosalita	978.1079	.092 45*	-15.45	
CAMPECHE					
WA 406	Campeche	978.6519	.636 71*	-15.19	
WA 409	Ciudad del Carmen	978.5676	.552 80*	-14.80	
CHIAPAS					
WA 435	Tapachula	978.3186	.304 97*	-13.63	
CHIHUAHUA					
WA 417	Ciudad Juarez	979.0697	.055 26*	-14.44	
WA 429	Parral	978.5372	.523 84*	-13.36	
COAHUILA					
WA 430	Saltillo	978.5785	.563 70*	-14.80	
WA 437	Torrean	978.6399	.625 50*	-14.40	
DISTRITO FEDERAL					
GW 43	Mexico Un. "A"	977.9414	.926 50	-14.90	
GW 41	Tacubaya "D"	977.9419	.927 15	-14.75	
WA 189	Int'l. AP "J"	977.9701	.955 42	-14.68	
WA 489	Int'l. AP "L"	977.9705	.955 99	-14.51	
GW 42	Paso de Cortes "A"	977.5711	.556 36	-14.74	
GW 42B	Cortes Mon "C"	977.6536	.638 32	-15.28	Site?
JALISCO					
WA 413	Guadalajara	978.2203	.207 66*	-12.64	Site?
NAYARIT					
WA 436	Tepic	978.4682	.453 22*	-14.98	

Table 24 (cont.)

Mexico (cont.)

		Woollard and Rose	IGSN 71	Diff
NUEVO LEON				
GW 21	Monterrey "A"	978.8055	.790 69	-14.81
WA 190	Monterrey AP "J"	978.8617	.847 05	-14.65
OAXACA				
WA 435	Tehuantepec	978.4190	.404 04*	-14.96
SAN LUIS POTOSI				
WA 431	San Luis Potosi AP "J"	978.2096	.194 70	-14.90
WA 492	San Luis Potosi "K"	978.2097	.194 78	-14.92
WA 433	Tamuin	978.7589	.744 43*	-14.47
SINOLA				
WA 411	Culican	978.9315	.917 64*	-13.86
WA 420	Los Mochis	978.0199	.005 75*	-14.15
TABASCO				
WA 441	Villahermosa	978.5278	.513 39*	-14.41
TAMAULIPAS				
WA 426	Nuevo Laredo "K"	979.0770	.062 55	-14.45
VERA CRUZ				
WA 440	Vera Cruz	978.5613	.545 89*	-15.41
YUCATAN				
WA 423	Merida	978.6990	.683 51*	-15.49

Table 25

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values on an Areal basis in Central America and the West Indies

		Woollard and Rose	IGSN 71	Diff.
CENTRAL AMERICA				
CANAL ZONE				
WH 1056	Balboa Rodman NB "R"	978.2376	.222 54	-15.06
WH 1057	Cristobal	978.2536	.238 56*	-15.04
GW 92	Ft. Clayton Pend. "A"	978.2417	.226 70	-15.00
US Pend	Ft. Clayton Pend. "O"	978.2391	.224 00	-15.10
WA 4004	Albrook AFB "S"	978.2427	.227 72	-14.98
COSTA RICA				
WA 4049	Golfito	978.2389	.223 98*	-14.92
WA 4043	Liberia	978.1967	.181 79*	-14.91
WA 4046	Los Chiles	978.2443	.229 37*	-14.93
WA 4045	Nicoya	978.2728	.257 87*	-14.93
WA 4007	San Jose "K"	978.9792	.964 36	-14.84
GUATAMALA				
WA 4019	Chahel	978.3717	.356 74*	-14.96
WA 4022	Dos Lagunas	978.4820	.467 02*	-14.98
WA 4011	Guatamala C. "K"	977.9815	.966 80	-14.70
WA 4021	Santo Torbido	978.4020	.387 04*	-14.96
HONDURAS				
WA 4034	Ruinas de Sopan	978.2140	.199 39*	-14.61
WA 4012	Tegucigalpa	978.0869	.072 32*	-14.58
NICARAGUA				
WA 4013	Manaqua	978.2858	.270 92*	-14.88
	Manaqua "K"	978.2858	.270 76	-15.04
WA 4036	San Juan del Sur	978.2609	.245 98*	-14.92
WA 4037	Siuna	978.3258	.310 56*	-15.24
PANAMA				
WA 4050	David	978.1616	.146 60*	-15.00
WA 4014	Panama, Tocumen AP	978.2665	.251 44*	-15.06

Table 25 (cont.)

Central American and West Indies (cont.)

		Woollard and Rose	IGSN 71	Diff.
WEST INDIES				
CUBA				
WA 4009	Guantanamo "K"	978.7451	.730 55	-14.55
LEEWARD ISLANDS				
WA 4001	Antiqua "B"	978.6544	.638 91	-15.48
PUERTO RICO				
WA 4015	Ramey AFB "K"	978.6602	.645 01	-15.19
WA 4016	San Juan "J"	978.6845	.669 88	-14.62
TRINIDAD				
WA 4003	Port au Spain "J"	978.1622	.146 88	-15.32

preparing the table because of differences of 1.0 mgal or more from the mean. As seen from the distribution plot (Figure 13E) there is a suggestion of a bimodal distribution, but the bulk of the values (22) define a normal distribution centered on a mean difference value of 15.0 mgal. Of this group 17 (77 percent) of the values fell within the bounds of ±0.1 mgal from the mean. The difference between this group of values and those occurring at 14.6 mgal can be attributed to the difference in bases used; the lower value group being based on direct ties from the United States, and the higher value group being based on Panama.

SUMMARY ON COMPARISON OF WOOLLARD AND ROSE VALUES WITH IGSN 71 VALUES IN NORTH AMERICA

As noted in considering the differences between the Woollard and Rose (1963) values and the IGSN 71 values on an areal basis for Alaska, Canada, the continental United States (excluding Alaska), Mexico, Central America and the West Indies, only two areas are characterized by pronounced median values for the differences in values relative to the IGSN 71 values. These two areas are Canada where the differences describe a normal Gaussian distribution and the United States where the distribution is slightly skewed. However, the median difference between the Woollard and Rose values and the IGSN 71 values for both areas is the same (14.61 mgal) as is the spread in values for 65 percent of the data which does not exceed ±0.1 mgal from the mean value. These results therefore corroborate the relations defined earlier for the gravity standardization ranges in North America as regards a mean deviation in datum of 14.6 ±0.1 mgal with no difference in gravity standard between the Woollard and Rose values and the IGSN 71 values at least between Point Barrow, Alaska and Monterrey, Mexico. The overall areal data for Alaska do not conform to this model except in terms of the median average value of 14.56 mgal .* This non-conformity is the result of several factors. These factors apply also to Mexico where there is no central tendency for a dominant difference in values relative to the IGSN 71 values, but only a broad spectrum of values having about the same frequency of occurrence. The following remarks will apply to both Alaska and Mexico:

(1) the data for both areas were taken for the most part in the period 1950-1955 with early model high range gravimeters (North American and Worden instruments in particular) whose response characteristics were imperfectly known and whose calibrations were poorly established. (2) because of limited funds the control base net was established as closure loops rather than in ladder sequence and as a result tares could not be located exactly or even separated from instrumental drift in many cases. (3) in both areas several sites were used as take-off points for expanding the network of values, and as a result any undetected error at any of these sites was automatically transmitted to all subsequent sites.

The proof of these points is obvious when the differences in the Woollard and Rose values from the IGSN 71 values are plotted as a function of absolute gravity as shown in Figures 14A and 14B for Alaska and Mexico respectively. Both plots show similar parallel alignments of values that are offset from each other. The slopes defined suggest significant difference in the calibration standard used from that represented in the IGSN 71 values, and the offsets indicate tares that had not been detected in the sub-bases used in expanding the network of stations. As seen for the similar plot for the differences in values for the United

*Although it approaches the 14.6 mgal median value, the median average value of 14.56 mgal has an average spread of ± 0.25 mgal .

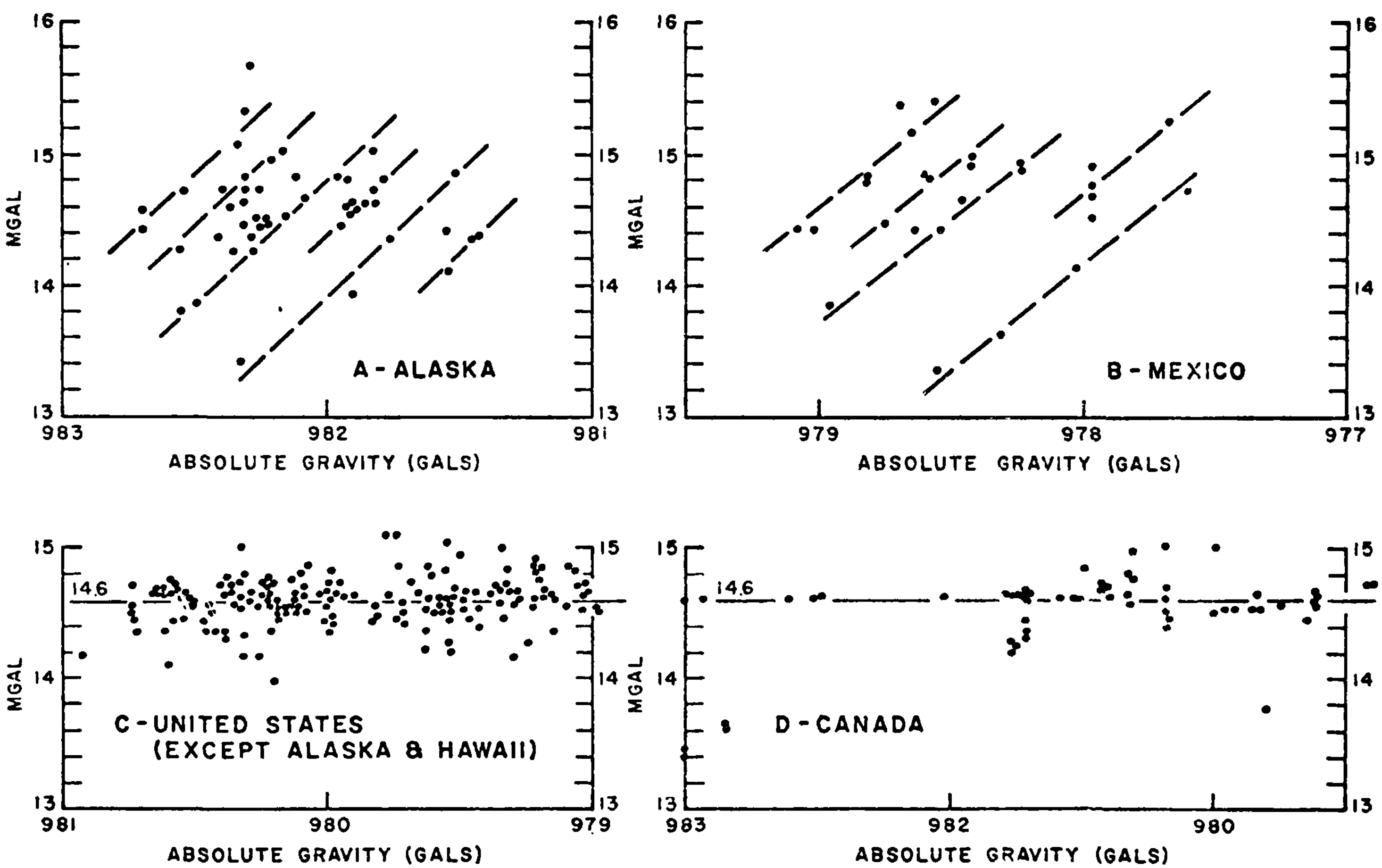


Fig. 14. Difference in Woollard and Rose values as a function of absolute gravity on an areal basis. A - Alaska; B - Mexico; C - United States; D - Canada.

States (Figure 14C), there is a suggestion that there may have been something of the same nature involved also in some of these values; however, this is not evident in the Canadian data (Figure 14D) except in terms of tare incorporated in some of the values as those for Eureka and Resolute Bay in the Northwest Territory which are offset by about one milligal from the other values.

COMPARISON OF WOOLLARD AND ROSE (1963) VALUES WITH IGSN 71 VALUES ON AN AREAL BASIS IN SOUTH AMERICA

In Table 26 the Woollard and Rose (1963) values are compared on a country by country basis in South America with the IGSN 71 values. Figure 15 shows the distribution plots for the differences in values for each country. Where there were only single or no more than 3 comparative values for a country as in Surinam, Guyana, French Guiana, Paraguay and Uruguay these values were incorporated with the data for the adjacent country. As seen, there is no dominant difference in the Woollard and Rose values and the IGSN 71 values for either Ecuador or Argentina, and whereas a difference of 14.9 mgal is dominant in Venezuela, Brazil and Bolivia, the dominant value in Colombia is 14.8 mgal that in Peru is 15.0 mgal, and that in Chile about 15.35 mgal. As these differences could be related to the calibration difference brought out for the Andean series of gravity standardization measurements and the tares implied in the Atlantic coastal series, the data were examined in terms of their relation to absolute changes in gravity. Figure 16A is the plot for the combined data for Colombia, Ecuador, Peru, Bolivia and Chile with the values for each country coded so they can be identified. For comparative purposes a mean line having a slope of 0.2 mgal per 1000 mgal change (the calibration difference brought out

Table 26

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values on an Areal basis in South America

		Woollard and Rose	IGSN 71	Diff.
ARGENTINA				
WA 6001	Bahia Blanca "K"	980.0683	.052 78	+15.52
	Bahia Blanca	.0683	.052 88*	+15.42
GW 98A	Buenos Aires "A"	979.7048	.690 03	+14.77
Univ	Meter. Obs. "C"	979.7060	.691 16	+14.84
WA 6002	Ezeisa AP "K"	979.7317	.716 75	+14.95
WA 6005	Comodoro Riva. "K"	980.6634	.648 03	+15.37
WA 6004	Cordoba "K"	979.3271	.312 34	+14.76
Univ Base	La Plata "D"	979.7517	.736 85	+14.85
WA 6007	Mar del Plata	980.0181	.002 73	+15.37
WA 6008	Oran "K"	978.6381	.623 48	+14.62
WA 6010	Rio Gallegos "K"	981.2066	.191 38	+15.22
	Rio Gallegos	.2066	.191 34*	+15.26
WA 6011	Rio Grande "L"	981.4330	.417 22	+15.78
WA 6012	Salta "K"	978.4985	.483 95	+14.55
WA 6013	San Julian "L"	981.0137	.997 64	+16.06
WA 6014	Santa Cruz	981.0465	.030 24*	+16.26
WA 6015	Santiago del Estero	979.0986	.084 33*	+14.27
WA 6016	Tartagal	978.5938	.578 79	+15.01
WA 6017	Trelew "K"	980.4539	.438 70	+15.20
WA 6018	Tucuman "K"	978.9060	.982 06	+13.94
Pend	Ushuaia Pent. "A"	981.4807	.465 39	+15.31
BOLIVIA				
WA 6165	Acension	978.3905	.375 55*	+14.95
WA 6167	Camiri	978.3535	.338 73*	+14.77
WA 6173	Cobija	978.1685	.153 60*	+14.90
WA 6162	Cochabamba	977.7945	.779 94*	+14.56
GW 95	La Paz "A"	977.4671	.452 19	+14.91
WA 6134	Braniff AP "K"	977.3528	.338 00	+14.80
WA 6020	Pan Am AP "L"	977.3487	.334 02	+14.68
WA 6175	Magdalena	978.3308	.315 92*	+14.88

Table 26 (cont.)

South America (cont.)

		Woollard and Rose	IGSN 71	Diff.
WA 6172	Riberalta	978.2378	.222 88*	+14.92
WA 6169	San Ignacio, M	978.3337	.318 76*	+14.94
WA 6166	San Javier	978.3367	.321 82*	+14.88
WA 6174	San Joaquin	978.2975	.282 52*	+14.98
WA 6170	San Ana	978.3388	.323 85*	+14.95
WA 6021	Santa Cruz "K"	978.3639	.349 07	+14.83
WA 6141	Santa Cruz "J"	978.3643	.349 44	+14.86
WA 6163	Sucre	977.7915	.776 70*	+14.80
WA 6168	Trinidad	978.3374	.322 70*	+14.70
BRAZIL				
WA 6022	Acu	978.0839	.069 02*	+14.88
WA 6023	Alegrete	979.2926	.277 41*	+15.19
WA 6024	Anapolis	978.1489	.134 01	+14.89
WA 6026	Aracati	978.0979	.083 02*	+14.88
WA 6027	Aracatuba	978.5808	.565 80*	+15.00
WA 6028	Aragarcas	978.3196	.304 66*	+14.94
WA 6030	Araguari	978.2764	.261 47*	+14.93
WA 6031	Bage	979.4128	.397 58*	+15.22
GW 108	Belem "A"	978.0374	.022 24	+15.16
WA 6032	Belem AP "K"	978.0342	.018 97	+15.23
WH 1012	Tide Gage "O"	978.0397	.024 59	+15.11
WH 1055	Pier "N"	978.0399	.024 63	+15.27
WA 6033	Belo Horizonte	978.4003	.385 50*	+14.80
WA 6035	Brasilia "K"	978.1013	.086 07	+15.23
WA 6142	Brasilia "J"	978.1001	.084 92	+15.18
WA 6036	Caceres	978.3968	.381 84*	+14.96
WA 6037	Campo Grande	978.5065	.491 52*	+14.98
WA 6039	Campos "J"	978.7326	.717 49	+15.11
WA 6041	Caravelas "J"	978.5270	.511 46	+15.54
WA 6042	Carolina "J"	978.0461	.031 11	+14.99
WA 6029	Conceicao A	978.0449	.030 03*	+14.87
WA 6043	Cruz Alta	979.1207	.105 55*	+15.15
WA 6044	Cruzeiro do Sul	978.1081	.093 21*	+14.89
WA 6045	Cuiaba	978.3590	.344 05*	+14.95

Table 26 (cont.)

South America (cont.)

		Woollard and Rose	IGSN 71	Diff.	
WA 6046	Curitiba	978.7895	.774 45*	+15.05	
WA 6047	Esplanada	978.2614	.246 48*	+14.92	
WA 6048	Fazenda Si Juan	978.4820	.467 02*	+14.98	
WA 6051	Florinapolis "J"	979.1338	.118 93	+14.87	
WA 6053	Fortaleza "J"	978.0822	.067 81	+14.39	site?
WA 6055	Goiania "J"	978.2403	.225 40	+14.90	
WA 6056	Grajau	977.9848	.969 95*	+14.85	
WA 6057	Guajara Mirim	978.2172	.202 28*	+14.92	
WA 6058	Iguassu Falls	978.9191	.904 01*	+14.99	
WA 6059	Ilheus	978.4617	.446 87*	+14.83	
WA 6060	Imperatriz	978.0195	.004 39*	+15.11	
WA 6154	Itacoatiara	978.0165	.001 64*	+14.86	
WA 6061	Joao Pessoa "J"	978.1443	.129 03	+15.27	
		978.1443	.129 18*	+15.12	
WA 6062	Livramento	979.3357	.320 50*	+15.20	
WA 6155	Londrina	978.6518	.636 77*	+15.03	
WA 6063	Maceio	978.1429	.128 07*	+14.83	
WA 6064	Manaus "J"	978.0213	.006 16	+15.14	
		978.0213	.006 27*	+15.03	
WA 6065	Maraba	978.0364	.021 53*	+14.87	
WA 6066	Mossoro	978.0926	.077 45*	+15.15	
WA 6067	Natal	978.1151	.099 85*	+15.25	
WA 6068	Paracatu	978.2596	.244 67*	+14.93	
WA 6069	Parana	978.1699	.155 00	+14.90	
WA 6070	Parnaiba	978.0372	.020 62*	+16.58	site?
WA 6071	Pedro Afonso	978.0951	.081 79*	+14.31	
WA 6072	Peixe	978.1981	.183 03*	+15.07	
WA 6074	Porto Alegre "J"	979.3158	.300 78	+15.02	
WA 6159	Porto Guaira	978.8091	.794 03*	+15.07	
WA 6075	Porto Nacional "J"	978.1605	.145 44	+15.06	
WA 6076	Porto Seguro	978.4661	.451 12*	+14.98	
WA 6077	Porto Velho	978.1444	.129 51*	+14.89	
WA 6079	Recife "J"	978.1665	.151 25	+15.25	

Table 26 (cont.)

South America (cont.)

		Woollard and Rose	IGSN 71	Diff.	
WH 1059	Harbor "M"	978.1777	.162 52	+15.18	
WA 6080	Rio Branco	978.1582	.143 30	+14.90	
GW 109	Rio de Janeiro "A"	978.8047	.789 90	+14.80	
WA 6082	Galeao AP "J"	978.7978	.783 05	+14.75	
WA 6081	S. Dumont "L"	978.8084	.793 55	+14.85	
WH 1060	Pier Praca N. "O"	978.8076	.792 78	+14.82	
WA 6083	Salvador "J"	978.3443	.329 43	+14.87	
WA 6084	Santa Maria	979.2771	.261 91	+15.19	
WA 6153	Santarem	978.0468	.031 93*	+14.87	
WA 6086	Sao Borja	979.2040	.188 84*	+15.16	
WA 6151	Sao Luis	977.9901	.975 52*	+14.58	
WA 6088	Sao Mateus	978.5719	.556 90*	+15.00	
WA 6090	Sao Paulo "M"	978.6508	.635 56	+15.24	site?
		978.6508	.636 23*	+14.57	
WA 6091	Sena Madureira	978.1569	.142 00*	+14.90	
WA 6092	Tarauaca	978.1403	.125 41*	+14.89	
WA 6149	Tefe "J"	978.0472	.031 88	+15.32	
WA 6093	Teresina	978.0320	.01710*	+14.90	
WA 6094	Tocantinapolis	978.0440	.029 13*	+14.87	
WA 6095	Tocantinia	978.1092	.094 31*	+14.89	
WA 6096	Tres Lagoas	978.5717	.556 70*	+15.00	
WA 6097	Uberaba	978.3609	.345 39*	+15.51	
WA 6158	Uruguiana	979.3075	.292 31*	+15.19	
WA 6100	Villa Bella	978.3408	.325 85*	+14.95	
WA 6101	Vitoria "J"	978.6537	.638 25	+15.45	
WA 6102	Xabantina	978.2837	.268 77*	+14.93	
WA 6103	Xapuri	978.1898	.174 89*	+14.91	
CHILE					
GW 99	Antofogasta "A"	978.9045	.889 52	+14.98	
WA 6105	Cerro Moreno AP "K"	978.8853	.870 30	+15.00	
WA 6135	Old AP "L"	978.8830	.868 04	+14.96	
WA 6106	Arica, Old AP "N"	978.5111	.495 82	+15.28	
WA 6144	Intl AP "L"	978.4939	.478 54	+15.36	

Table 26 (cont.)

South America (cont.)

		Woollard and Rose	IGSN 71	Diff	
WA 6160	Concepcion	979.9698	.954 44*	+15.36	
WA 6147	Puerto Montt "J"	980.2976	.282 22	+15.38	
WA 6148	Chameza AP "K"	980.3041	.288 74	+15.36	
GW 97	Punta Arenas "A"	981.3159	.300 49	+15.41	
WA 6108	Chabunco AP "K"	981.3122	.296 70	+15.50	
WA 6136	Chabunco AP "L"	981.3130	.297 61	+15.39	
WH 1019	Port Adm. "N"	981.3363	.320 81	+15.49	
GW 96	Santiago "A"	979.4294	.414 11	+15.29	
WA 6110	Los Cerillos AP "K"	979.4500	.434 68	+15.32	
WA 6109	Los Cerillos "J"	979.4493	.434 24	+15.06	
WH 1020	Valparaiso Pier "K"	979.6362	.620 87	+15.33	
WH 1058	Valpariso L. H. "L"	979.6342	.618 90	+15.30	
	COLOMBIA				
WA 6111	Barranquilla "J"	978.2265	.211 56	+14.94	
WH 1066	Port "K"	978.2393	.224 27	+15.03	
GW 106	Bogota "A"	977.4049	.390 11	+14.79	
WA 6112	Techo AP "J"	977.4017	.386 91	+14.76	
WA 6145	Eldorado AP "K"	977.3954	.380 59	+14.81	
WA 6113	Cali "J"	977.8197	.804 89	+14.81	
WA 6114	Cartagena	978.1965	.181 59*	+14.91	
WA 6181	Chafurray	977.9887	.973 84*	+14.81	
WA 6116	Ipiales	977.2532	.238 53*	+14.67	
Pend	Medellin	977.7547	.740 66*	+14.24	site?
WA 6118	Pereira	977.7740	.759 20*	+14.80	
WA 6119	Popayan "K"	977.5998	.584 49	+15.31	site?
WA 6179	San Juan	977.8964	.881 57*	+14.83	
WA 6178	Villavicencio	977.8676	.852 77*	+14.83	
	ECUADOR				
WA 6120	Guayaquil "M"	978.1391	.123 71	+15.39	
WA 6146	Guayaquil AP "K"	978.1447	.129 34	+15.46	
WA 1067	Pier "N"	978.0918	.076 30	+15.50	
WA 6177	Manta	978.1017	.086 81*	+14.89	
GW 106	Quito "A"	977.2777	.263 19	+14.51	

Table 26 (cont.)

South America (cont.)

		Woollard and Rose	IGSN 71	Diff
WA 6121	Panagra AP "J"	977.2860	.271 44	+14.56
WA 6139	Mariscal Sucre AP	977.2849	.270 38*	+14.52
	FRENCH GUIANA			
WA 6122	Cayenne	978.0387	.023 83*	+14.87
	GUYANA (British Guiana)			
WA 6104	Georgetown "K"	978.0909	.075 55	+15.35
WA 6143	New Term. "J"	978.0911	.075 70	+15.40
WH 1062	Harbor "L"	978.1179	.102 48	+15.42
	PARAGUAY			
WA 6123	Asuncion "J"	978.9583	.943 12	+15.18
	PERU			
WA 6124	Arequipa "K"	977.7165	.701 73	+14.77
WA 6125	Iquitos "J"	978.0876	.072 11	+15 49
GW 93	Lima "A"	978.2830	.267 94	+15.06
WA 6126	Limatambo AP "J"	978.2791	.264 08	+15.02
WA 6140	Callao Intl "K"	978.3072	.292 18	+15.02
WH 1068	Callao Pier "M"	978.3127	.297 79	+14.91
WA 6176	Pucallpa	978.0550	.040 13*	+14.87
WA 6127	Talara	978.1336	.118 64*	+14.96
	SURINAM			
WA 6128	Paramaribo "J"	978.0471	.033 50	+13.60 site?
	URAGUAY			
WA 6129	Montevideo "K"	979.7465	.731 56	+14.94
	VENEZUELA			
WA 6130	Barcelona	978.1505	.135 63*	+14.87
WA 6193	Caicara	978.1247	.111 08*	+13.62 site?
WA 6191	Calabozo	978.1679	.153 69*	+14.21 site?
GW 107	Caracas "A"	978.0399	.024 72	+15.18
WA 6131	Maiquetia AP "K"	978.2460	.231 06	+14.94
WH 1071	La Guayra Hrb. "L"	978.2522	.237 24	+14.96
WA 6185	Casigua	978.1170	.102 12*	+14.88
WA 6190	Coro	978.2374	.222 48*	+14.92

Table 26 (cont.)

South America (cont.)

		Woollard and Rose	IGSN 71	Diff	
WA 6133	Maturin "J"	978.0112	.966 31	+14.89	
WA 6187	Merida	977.7506	.735 92*	+14.68	
WA 6194	Puerto Paez	978.0818	.066 92*	+14.88	
WA 6184	San Antonio	977.9430	.927 57*	+15.43	site?
WA 6192	San Fernando Apure	978.1412	.126 30*	+14.90	

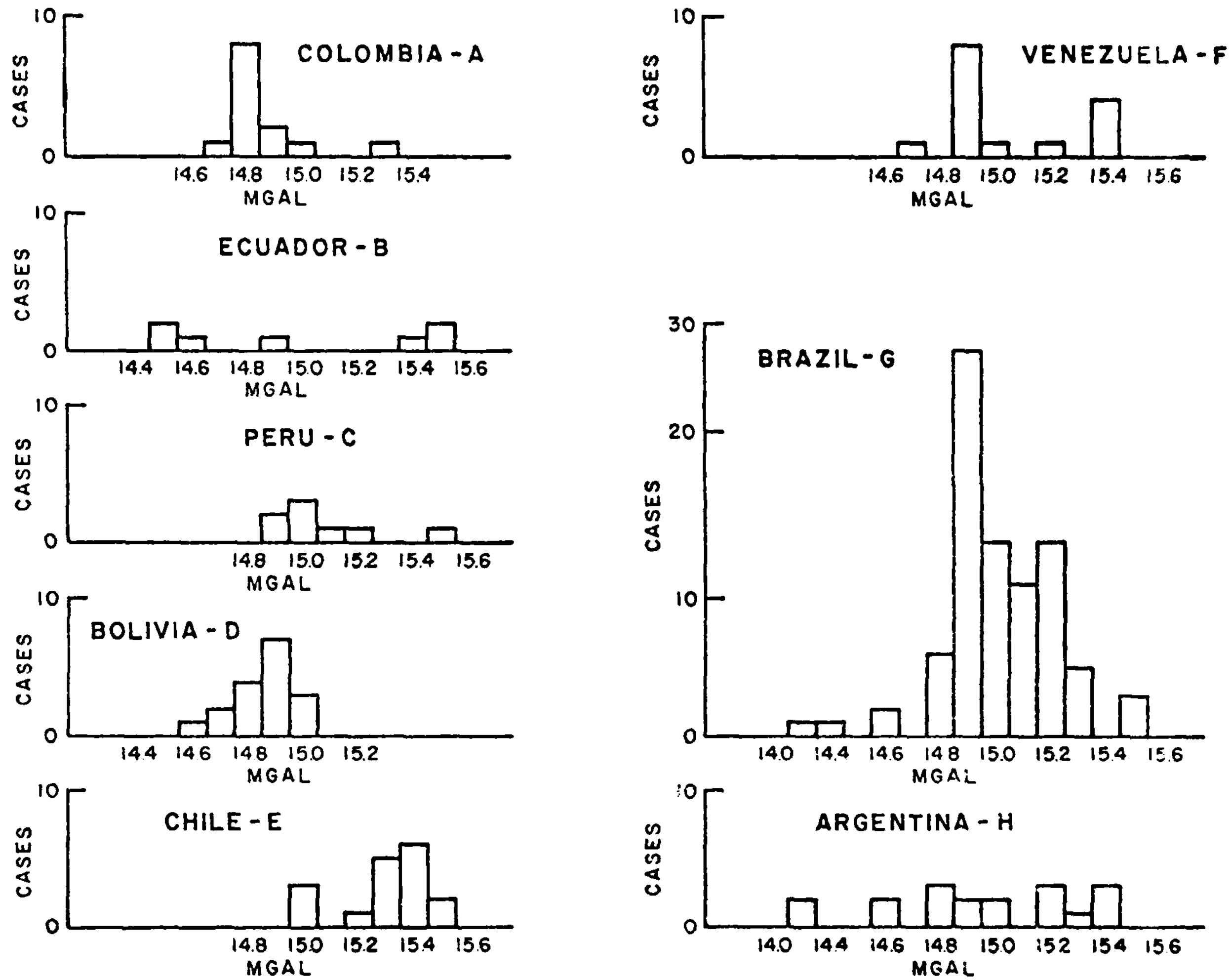


Fig. 15. Distribution plots of the differences in Woollard and Rose values and IGSN 71 values on an areal basis in South America. A- Colombia; B- Ecuador; C- Peru; D- Bolivia; E- Chile; F- Venezuela; G- Brazil; H- Argentina.

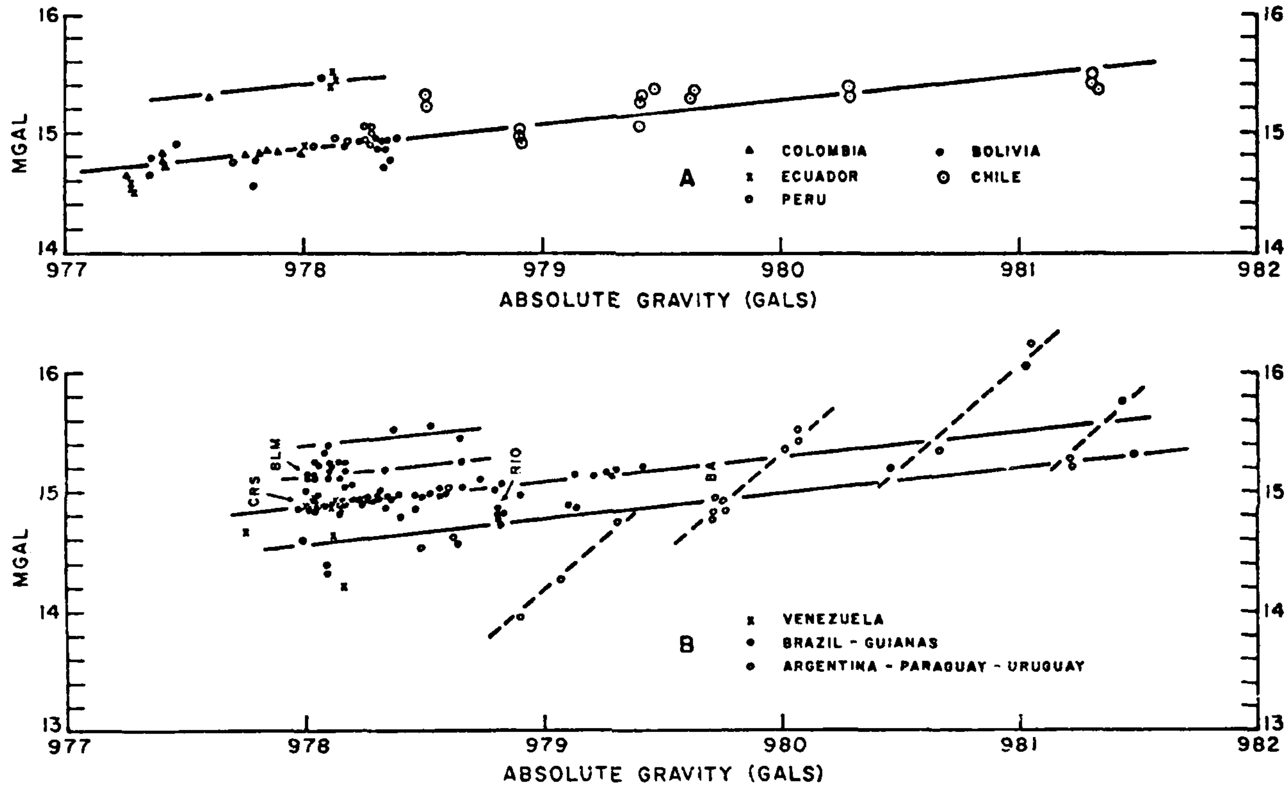


Fig. 16. Difference in Woollard and Rose values and IGSN 71 values as a function of absolute gravity in South America. A- Combined data for Colombia, Ecuador, Peru, Bolivia, and Chile. B- Combined data for Venezuela, the Guianas, Brazil, Paraguay, Uruguay and Argentina.

for the Andean series of gravity standardization sites) is superimposed to give a best fit to the values. As seen, except for a few sites, the data fit this slope remarkably well. The only difference in an equation describing the relation from that based on the gravity standardization sites would be in the 15.0 mgal absolute gravity intercept. In this case the intercept would be at 978.65 gals rather than 978.5 gals. The reality of the difference in calibration for the instruments used in South America in the Andean region thus appears to be well established.

Figure 16B is a similar combined plot of the differences in values for Venezuela, Brazil (including the values for Surinam, Guyana and French Guiana) and Argentina (including the values for Paraguay and Uraguay). As is clearly brought out by the data for Brazil and Venezuela, the same slope (including the 15 mgal intercept value) noted in the data for the Andean countries is present also in these data. This slope, however, is not obvious in the data for Argentina which give at least in part a pattern of differences similar to those noted for Alaska and Mexico both as regards the high slope value suggested as well as apparent tares. That the superimposed pattern noted in Alaska and Mexico also characterizes much of the data for Argentina can be attributed to the fact that most of the observations in Argentina were made in 1950 with the same early high range Worden gravimeter that was used in Alaska and Mexico. The fact that this pattern is not seen in the data for Brazil and the Andean countries of South America is because the measurements in these areas were made with second generation Worden gravimeters and adjusted later through repeat measurements at key points using LaCoste Romberg gravimeters on a different calibration standard, but apparently still not adequately calibrated. Also

Figure 16 shows that two apparent tares occur between Belem and Rio de Janeiro. Four equally displaced offsets in the Brazilian data, however, suggest a series of mistakes in replacing the main spring reading dial on the early Worden gravimeters and amounted to a reset in the readings for the equivalent of half a dial turn on the eccentric screw.

COMPARISON OF WOOLARD AND ROSE AND IGSN 71 VALUES ON AN AREAL BASIS IN EUROPE

Table 27 presents the differences in the Woolard and Rose (1963) values relative to the IGSN 71 values in Europe. The distribution plot of the differences in values (Figure 17A) suggests a bimodal distribution with an overall mean difference of 14.7 mgal . When the differences are plotted as a function of absolute gravity as shown in Figure 18A, it is suggested that there are two parallel alignments of values having a slope of about 0.2 mgal per 1000 mgal change in gravity which are separated by 0.4 mgal. As the upper alignment including Cyprus, Madrid, Rome, Paris, London, Glasgow and Edinburgh passes through the values for Iceland, which is a port of call for many of the connections to Europe from North America, this change of value is included. The lower line which included all of the Scandinavian sites except Stockholm as well as Hamburg and Geneva, although showing the same slope, apparently incorporated a tare of 0.4 mgal in the connections from London. This previously undetected pattern of error appears to be the explanation for the apparently long wave length changes in the differences in the Woollard and Rose values and IGSN 71 values noted for the pendulum sites in Europe.

Table 27

Comparison of Woollard and Rose Cravimeter Values and IGSN 71

Values on an Areal Basis in Europe

		Woollard and Rose	IGSN 71	Diff. Mgal
CYPRUS				
Pend.	Nicosia	979.8492	.83449*	+14.71
DENMARK				
GW 64	Copenhagen "B"	981.5577	.54319	+14.51
WA 5004	Kastrup AP "J"	981.5573	.54275	+14.55
WA 5059	Kastrup AP "L"	981.5568	.54226	+14.54
EIRE (Ireland)				
Pend. Base	Dublin (Dunsink Obs.)	981.3891	.37478*	+14.32
FINLAND				
Pend. Base	Helsinki "A"	981.9152	.90059	+14.61
WA 5019	Seutula AP "S"	981.9248	.91009	+14.71
FRANCE				
WA 5022	Bordeaux	980.5816	.56694*	+14.66
WA 5023	Marseille "J"	980.4880	.47355	+14.45
GW 114	Paris "A"	980.9409	.92597	+14.93
Gm Base	Obs. "B"	980.9434	.92865	+14.75
Nat'l Base	Obs. "E"	980.9432	.92829	+14.91
WA 5058	Orly AP "N"	980.9160	.90101	+14.99
WA 5024	Le Bourget AP "J"	980.9502	.93534	+14.86
ITALY				
WA 5032	Naples "R"	980.2568	.24204	+14.76
GW 61	Rome "A"	980.3639	.34923	+14.67

Table 27 (cont.)

Europe (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
Nat'l Base Rome "B"		980.3619	.34722	+14.68
	Roca de Papa Obs. "C"	980.1929	.17843	+14.47
WA 5033	Ciampino Est "J"	980.3489	.33427	+14.63
WA 5034	Ciampino Ovest "M"	980.3478	.33319	+14.61
WA 5060	Fiumicino Int'l "N"	980.3765	.36176	+14.74
NETHERLANDS				
WA 5036	Amsterdam "J"	981.2882	.27340	+14.80
Pend.	DeBilt Obs.	981.2693	.25456*	+14.74
NORWAY				
GW 117	Bodo "A"	982.3873	.37265	+14.65
WA 5037	Airport "J"	982.3876	.37297	+14.63
GW 118	Hammerfest "A"	982.6324	.61762	+14.78
WH 1045	Indrefjord "J"	982.6301	.61548	+14.62
GW 68	Oslo "A"	981.9272	.91261	+14.59
WA 5038	Fornebu AP "J"	981.9367	.91620	+14.50
WA 5039	Tromso "K"	982.5710	.55711	+13.89 site?
Pend.	Trondheim "A"	982.1614	.14674	+14.66
WA 5040	Vaernes AP "K"	982.1523	.13779	+14.51
PORTUGAL				
GW 110	Lisbon "A"	980.0903	.07573	+14.57
WA 5041	Airport "K"	980.0796	.06512	+14.48
SPAIN				
Pend.	Madrid Astro. Obs. "A"	979.9812	.96652	+14.68
Gm Base	IGC "C"	979.9703	.95561	+14.69

Table 27 (cont.)

Europe (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
WA 5049	Barajas AP "J"	979.9988	.98414	+14.64
WA 5051	Torrejon AFB "M"	980.0072	.99251	+14.69
SWEDEN				
Pend.	Stockholm "A"	981.8465	.83143	+15.07
WA 5053	Bromma AP "J"	981.8455	.83066	+14.84
SWITZERLAND				
WA 5054	Geneva "J"	980.5889	.57444	+14.46
Pend.	Zurich Geod. Inst. "A"	980.6670	.65213	+14.87
WA 5055	Kloten AP "J"	980.6871	.67218	+14.92
UNITED KINGDOM				
Pend.Sta.	Aberdeen Univ.	981.6998	.68482*	+14.98
Pend.Sta.	Cambridge Univ.	981.2688	.25394*	+14.86
Pend.Sta.	Edinburgh Obs. "A"	981.5839	.56897	+14.93
WA 5047	Prestwick AP "J"	981.5784	.56351	+14.89
WA 5046	Prestwick MATS "K"	981.5758	.56113	+14.67
WA 5044	Glasgow "N"	981.6018	.58692	+14.88
GW 67	Teddington "A"	981.1966	.18178	+14.82
WA 5012	London AP (1) "J"	981.2003	.18558	+14.72
WA 5013	Old Term. "M"	981.2017	.18704	+14.66
Pend.	York	981.4183	.40380*	+14.50
WEST GERMANY				
GW 63	Bad Harzburg "A"	981.1803	.16550	+14.80
GW 63A	Braunschweig "C"	981.2668	.25184	+14.96

Tabel 27 (cont.)

Europe (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
GW 62	Frankfurt "A"	981.0610	.04632	+14.68
WA 5028	Airport "J"	981.0571	.04243	+14.67
WA 5064	Hamburg "J"	981.3943	.37969	+14.61
WA 5063	Hannover "K"	981.2875	.27261	+14.88

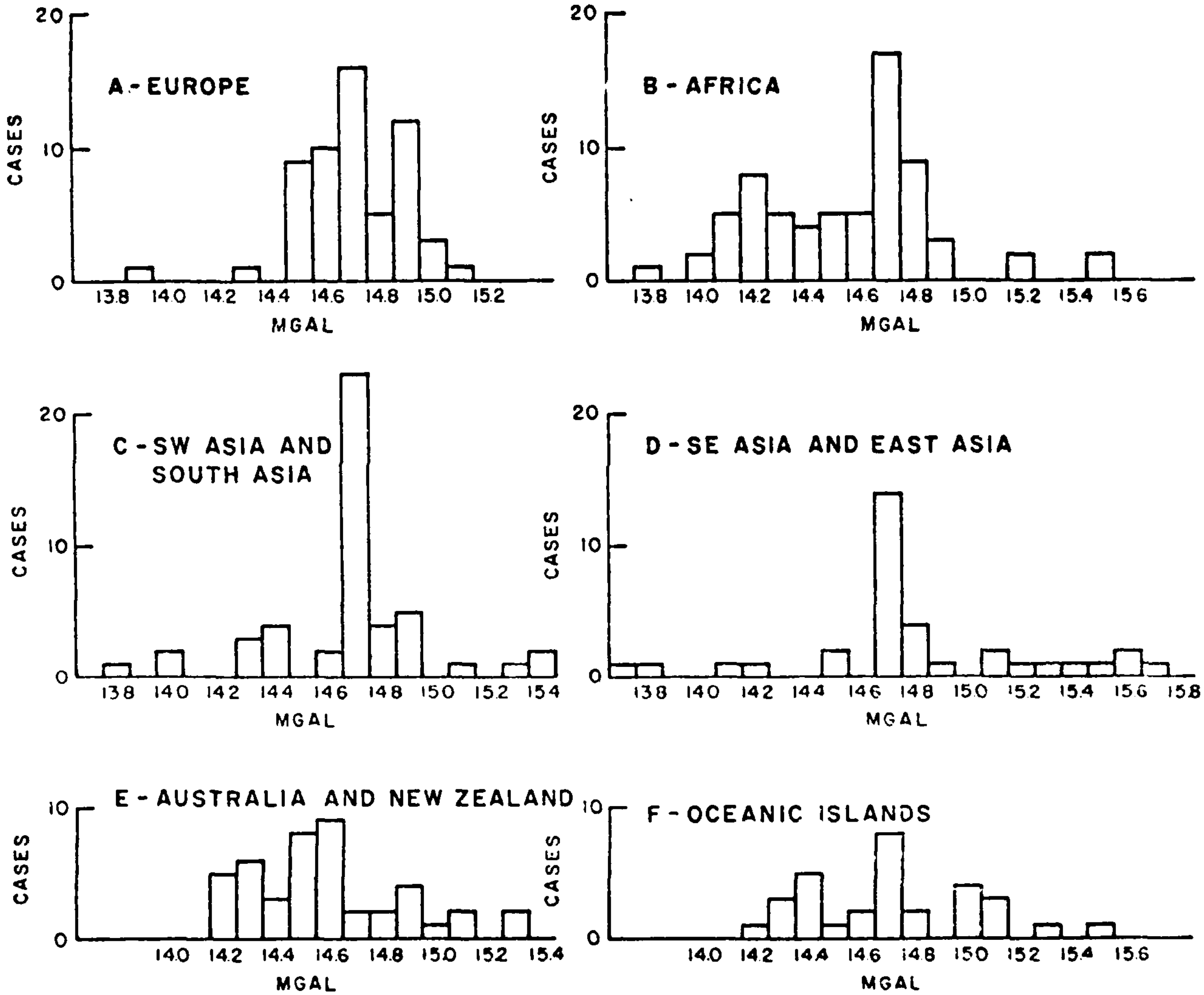


Fig. 17. Distribution plots of difference in Woollard and Rose (1963) gravimeter values and IGSN 71 values on an areal basis.

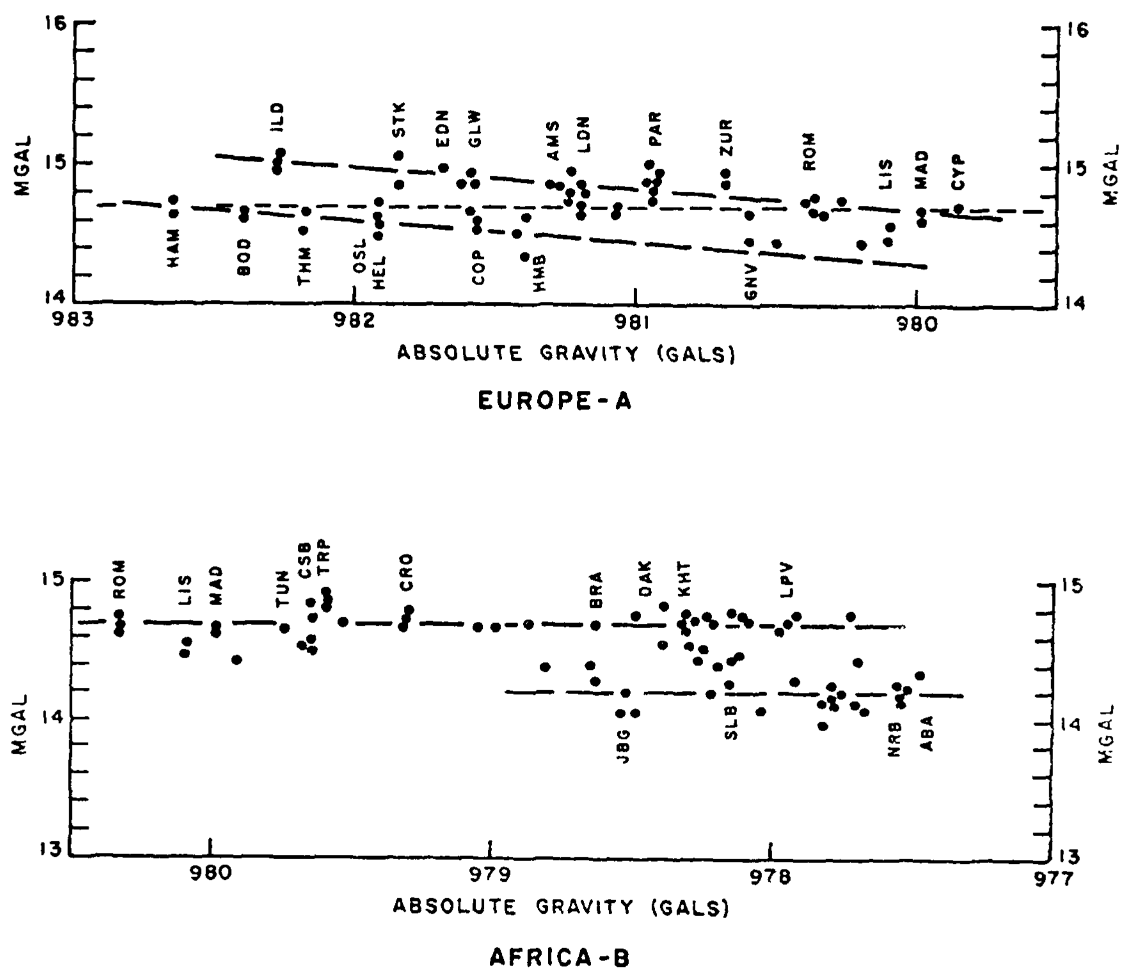


Fig. 18. Differences between Woollard and Rose and IGSN 71 values on an areal basis as a function of absolute gravity in A- Europe and B - Africa.

COMPARISON OF WOOLLARD AND ROSE AND IGSN 71 VALUES IN OTHER AREAS

COMPARISONS IN AFRICA

Table 28 presents the differences in the Woollard and Rose (1963) gravimeter values relative to the IGSN 71 values in Africa. As brought out in the distribution plot of the differences in values (Figure 17B), the dominant difference value is 14.7 mgal but there is also clearly a bi-modal distribution of values suggesting a tare in the data. This is brought out better in Figure 18B in which the differences in values are plotted as a function of absolute gravity. As seen, there are two parallel alignments indicating zero slope but separated by 0.5 mgal. The upper distribution has a mean value of 14.7 mgal and is continuous with the differences in values for Rome, Lisbon and Madrid and carries through Khartoum to Leopoldville and Capetown. The lower series with a mean difference in values of 14.2 mgal includes Johannesburg, Nairobi and Addis Ababa. As Addis Ababa and Johannesburg are at opposite ends of the continent, it appears that two tares of near equal magnitude and in the same sign are involved.

COMPARISONS IN SOUTHWEST ASIA AND SOUTHERN ASIA

Table 29 presents the differences in the Woollard and Rose (1963) gravimeter values relative to the IGSN 71 values in southwest Asia and southern Asia. As seen from the distribution plot of the differences in values (Figure 17C) the dominant difference value is 14.7 mgal . However, in Figure 19A in which the differences in values are plotted as a function of absolute gravity, a complex situation is brought out. This plot shows that the data for India stands out as being on a different calibration standard from all the other sites. The slope indicated is very similar to that noted in Alaska, Mexico and Argentina and there seems to be little reason to question its reality as it is duplicated in the offset values

Table 28

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values on an Areal Basis in Africa

		Woollard and Rose	IGSN 71	Diff. Mgal
ALGERIA				
WA 1001	Algiers "J"	979.9057	.89139	+14.31
EGYPT				
WH 1023	Alexandria Port	979.4331	.41921*	+13.89 site?
GW 69	Cairo "B"	979.2915	.27676	+14.74
WA 1002	Farouk AP "L"	979.3160	.30125	+14.75
WA 1004	Port Said "K"	979.4528	.43764	+15.16
WH 1026	Suez	979.3069	.29221*	+14.69
ETHIOPIA				
WA 1006	Addis Ababa "L"	977.4783	.46396	+14.34
GW 76	Asmara "A"	977.8194	.80545	+13.95
WA 1005	Mun. AP "J"	977.8224	.80826	+14.14
WA 1007	Debra Marcous	977.5107	.49416*	+15.54 site?
WA 1008	Gondar	977.7060	.65126*	+14.74
WA 1009	Tessenei "J"	978.1902	.17580	+14.40
GAMBIA				
WA 1011	Bathurst "J"	978.3535	.33875	+14.55
GHANA				
GW 112	Accra "A"	978.1059	.09141	+14.49
WA 1012	Airport "J"	978.1153	.10052	+14.78
GUINEA				
WA 1036	Conakry "J"	978.2264	.21094	+15.46

Table 28 (cont.)

Africa (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
KENYA				
GW 71	Nairobi "A"	977.5403	.52607	+14.23
Camb.	Bullard (L) "C"	977.5279	.51375	+14.15
WA 1014	Eastleigh "J"	977.5430	.52877	+14.23
WA 1015	West Civil "K"	977.5357	.52151	+14.19
LIBYA				
WA 1019	Benghazi	979.5264	.51170*	+14.70
GW 60	Tripoli "A"	979.5876	.57272	+14.88
WA 1021	Idris AP "L"	979.5379	.52300	+14.90
WA 1020	Wheeler AFB "K"	979.5876	.57274	+14.86
MALAGASY				
WA 9006	Tananarive "J"	978.2166	.20242	+14.18
MOROCCO				
WA 1023	Casablanca "J"	979.6428	.62796	+14.84
WA 1026	Tangier "J"	979.7492	.73401	+15.19 site?
MOZAMBIQUE				
WA 1027	Beira	978.6252	.61049*	+14.71
WA 1028	Lourenço Marques	979.0527	.03801*	+14.69
NIGERIA				
WA 1029	Kano "J"	978.1357	.12092	+14.78
RHODESIA				
WA 1042	Bulawayo "J"	978.2921	.27754	+14.56
WA 1043	Salisbury "J"	978.1484	.13414	+14.26
Pend.	Salisbury "A"	978.1481	.13365	+14.45
Pend.	Victoria Falls	978.2314	.21689*	+14.51

Table 28 (cont.)

Africa (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
	SENEGAL			
GW 111	Dakar M'Bour "B"	978.3852	.37039	+14.81
WA 1010	Yof AP "J"	978.4772	.46242	+14.78
	SOMALI			
WA 1041	Mogadiscio	978.0779	.06318*	+14.72
	SOUTH AFRICA			
WA 1055	Bloemfontein	978.8537	.83900*	+14.70
GW 74	Capetown "A"	979.6473	.63271	+14.59
Pend.	Royal Obs. "B"	979.6535	.63893	+14.57
WA 1057	Malan AP "J"	979.6462	.63145	+14.75
WA 1056	Wingfield AP "L"	979.6494	.63484	+14.56
GW 73	Johannesburg "A"	978.5495	.53546	+14.04
WA 1062	L. Smuts AP "K"	978.5503	.53610	+14.20
WA 1063	Kimberley "J"	978.8881	.87371	+14.39
WA 1067	Port Elizabeth	978.6514	.63571*	+15.69 site?
Pend.	Pretoria "A"	978.6296	.61530	+14.30
WA 1071	Upington	978.9831	.97040	+14.70
	SOUTHWEST AFRICA			
WA 1065	Ohopoho	978.2136	.19887*	+14.73
WA 1070	Tsumeb	978.2209	.20619*	+14.71
WA 1022	Windhoek	978.3210	.30629*	+14.71
	SUDAN			
GW 70	Khartoum "B"	978.3034	.28867	+14.73
GW 70A	Univ. Pend. "A"	978.3033	.28864	+14.66
WA 1045	Airport "L"	978.3034	.28865	+14.75

Table 28 (cont.)

Africa (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
WA 1047	Port Sudan "K"	978.6404	.62599	+14.41
	TANZANIA			
WA 1048	Dar-es-Salaam "K"	978.1165	.10011	+16.39 site?
WA 1049	Dodoma	977.7535	.73930*	+14.20
WA 1050	Mbeya "K"	977.6840	.66989	+14.11
WA 1051	Moshi "K"	977.7720	.75788	+14.12
WA 1052	Tabora "J"	977.6844	.66995	+14.45
	TUNISIA			
WH 1054	Sfax Harbor	979.7267	.71202*	+14.68
WA 1053	Tunis	979.9061	.89992*	+16.18 site?
	UGANDA			
WA 1054	Entebbe "J"	977.7241	.70984	+14.26
	ZAIRE (CONGO)			
GW 113	Leopoldville "A"	977.9146	.89982	+14.78
WA 1037	Int'l. AP "J"	977.9518	.93713	+14.67
WA 1038	Ndjili AP "M"	977.9429	.92820	+14.70
	ZAMBIA (N. RHODESIA)			
WA 1030	Abercorn "J"	977.6707	.65662	+14.08
WA 1031	Kasama "J"	977.7877	.77354	+14.16
WA 1033	Lusaka "J"	978.0534	.03932	+14.08
WA 1034	Ndola "K"	977.9126	.89830	+14.30

Table 29

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values on an Areal Basis in Southwest Asia and South Asia

		Woollard and Rose	IGSN 71	Diff. Mgal
BAHREIN				
WA 2002	Muharraq	979.0147	.99963	+15.07
SRI LANKA (CEYLON)				
	Colombo			
Pend.	Met. Obs. "B"	978.1328	.11724	+15.56
Pend.	Fr. Consul "C"	978.1403	.12454	+15.76
WA 2004	Ratmalana AP "J"	978.1323	.11690	+15.40
INDIA				
WA 2010	Amritzar "J"	979.3484	.33506	+13.34 site?
Pend.	Bangalore "A"	978.0294	.01389	+15.51
WA 2011	Bangalore "J"	978.0387	.02314	+15.56
WA 2013	Calcutta "J"	978.8077	.79281	+14.89
Nat'l Base	Dehra Dun "A"	979.0636	.04909	+14.51
WA 2016	Hyderabad "J"	978.3347	.31958	+15.12
WA 2017	Jammu	979.3041	.29004*	+14.06
Pend.	Madras "A"	978.2818	.26658	+15.25
WA 2018	Madras AP "J"	978.2804	.26516	+15.24
GW 59	New Delhi "A"	979.1363	.12155	+14.75
WA 2019	Palam AP "J"	979.1341	.11938	+14.72
WA 2020	Willingdon AP "K"	979.1379	.12316	+14.74
WA 2021	Srinagar	979.0443	.03013	+14.17

Table 29 (cont.)

Southwest Asia and South Asia (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
IRAN				
WA 2023	Tehran "J"	978.4491	.43068	+18.42 site?
IRAQ				
WA 2024	Ain Zalah	979.7840	.76933*	+14.67
WA 2025	Baghdad	979.5469	.53222*	+14.68
WA 2026	Basrah	979.3240	.30931*	+14.69
WA 2027	Kirkuk	979.5991	.64272*	+14.68
KUWAIT				
WA 2049	Al Kuwait	979.2688	.25411*	+14.69
LEBANON				
Pend.	Beirut "A"	979.6909	.67625	+14.65
WA 2050	Khalde AP_1 "J"	979.6934	.67864	+14.76
WA 2051	Khalde AP_2 "K"	979.6922	.67744	+14.76
PAKISTAN				
WA 2059	Karachi	978.9620	.94730*	+14.70
QATAR				
WA 2064	Dukhan	978.9528	.93810*	+14.70
SAUDI ARABIA				
WA 2067	Abu Hadriyah	979.1084	.09370*	+14.70
WA 2068	Dhahran	978.9990	.98430*	+14.70
WA 2069	Jidda	978.7556	.75222*	+13.38 site?
WA 2070	Ras Al Mishab	979.1696	.15491*	+14.69

Table 29 (cont.)

Southwest Asia and South Asia (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
TRUCIAL STATES				
WA 2075	Sharjah	978.9026	.88790*	+14.70
TURKEY				
WA 2076	Ankara "M"	979.9500	.93548	+14.52
WA 2077	Izmir	980.0231	.00842*	+14.68
YEMEN				
WA 2001	Aden "J"	978.3179	.30432	+13.58 site?

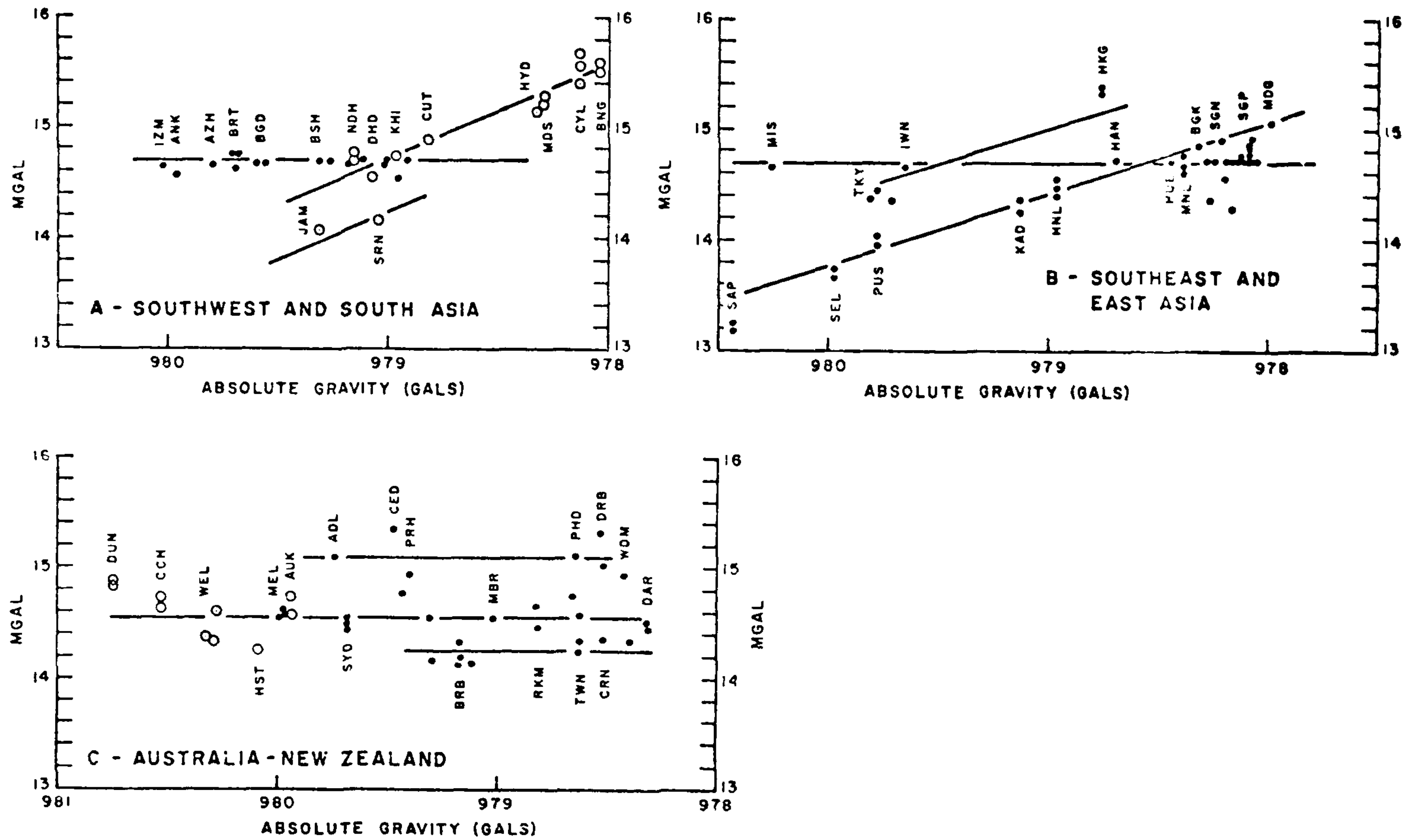


Fig. 19

Fig. 19. Difference between Woollard and Rose and IGSN 71 values on an areal basis as a function of absolute gravity in A– Southwest and South Asia; B– Southeast and East Asia; C– Australia and New Zealand.

for Jammu and Srinagar in Northern India. Problems remaining from the use of early Worden gravimeters were not eliminated in the final Woollard and Rose adjustment of values. Since much of the data included in this plot for the Persian Gulf area was also taken at the same time and with the same Worden gravimeter as used in India, there is a question in the writer's mind as to why the data for this area does not also display some of the characteristics seen in the data for India. The most probable explanation would appear to be that since the Persian Gulf sites were not reoccupied by groups other than oil companies who used the Woollard and Rose values for control, all of the available comparative data that went into the IGSN 71 adjustment indicated little or no error in the Woollard and Rose values and the mean difference relative to the IGSN 71 values fortuitously agreed with those for sites such as Beirut, Ankara, Karachi and New Delhi which had been reoccupied by non-oil company groups.

COMPARISONS IN SOUTHEAST ASIA AND EAST ASIA

In Table 30 the difference in the Woollard and Rose (1963) gravimeter values relative to the IGSN 71 values for sites in southeast Asia and east Asia are presented. Figure 17D shows the distribution plot and as in southwest Asia the dominant difference in values in 14.7 mgal . When the differences in values are plotted as a function of absolute gravity (Fig. 19B) two crosscutting distributions (one having a slope similar to that noted) in India are also present. Although the upper slope would appear to explain the apparently anomalous difference in values for Hong Kong on a tie from Tokyo, neither of these superimposed distributions gives a logical explanation for the anomalous difference at Sapporo which was

Table 30

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values on an Areal Basis in Southeast Asia and East Asia

		Woollard and Rose	IGSN 71	Diff. Mgal
	CAMBODIA			
WA 2003	Phnom Penh "J"	978.2390	.22308	+15.82
	FEDERATION OF MALAYSIA			
	Sabah (North Borneo)			
WA 2054	Jesselton	978.1279	.11318*	+14.72
WA 2055	Labuan Is.	978.0960	.08128*	+14.72
WA 2056	Sandakan	978.0914	.07668*	+14.72
	Sarawak			
WA 2065	Kuching	978.0763	.06158*	+14.72
WA 2066	Sibu	978.0790	.06428*	+14.72
	HONG KONG			
GW 101	Am. Consulate "A"	978.7677	.75231	+15.39
WA 2008	Kai-Tak AP "J"	978.7730	.75766	+15.34
Pend.	Kowloon Roy. Obs. "B"	978.7712	.75585	+15.35
	INDONESIA			
WA 3045	Djakarta	978.1644	.14968*	+14.72
	NEW CALEDONIA			
WA 7016	Tontouta	978.8590	.84430*	+14.70
	NEW GUINEA AREA			
	BISMARCK ARCHIPELAGO			
	New Britain Is.			
WA 3011	Rabaul	978.1643	.15001*	+14.29

Table 30 (cont.)

Southeast Asia and East Asia (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
	New Ireland Is.			
WA 3081	Kavieng	978.1668	.15208*	+14.72
	Papua			
WA 3069	Port Moresby "J"	978.2129	.19833	+14.57
	Terr. of New Guinea			
WA 3084	Aitape	978.1707	.15598*	+14.72
WA 3077	Goroka	977.6994	.68467*	+14.73
WA 3076	Lae	978.0140	.99614*	+17.86 site?
WA 3078	Madang	977.9701	.95504*	+15.06
WA 3086	Vanima	978.1997	.18498*	+14.72
WA 3079	Wewak	978.0965	.08158*	+14.92
	WEST IRIAN			
WA 3098	Biak Is.	978.1237	.10898*	+14.72
WA 3097	Hollandia	978.1721	.15737*	+14.73
WA 3099	Manokwari	978.0869	.07218*	+14.72
WA 3068	Noemfoor Is.	978.1409	.12618*	+14.72
WA 3096	Sarmi	978.1461	.13137*	+14.73
WA 3101	Sorong	978.1401	.12537*	+14.73
	PHILIPPINES			
GW 58	Clark AFB "A"	978.3969	.38230	+14.60
WA 2061	Clark MATS "J"	978.3965	.38183	+14.67
WA 2062	Manila Intl. AP "K"	978.3767	.36192	+14.78
WH 1048	Manila Pier "N"	978.3562	.34142	+14.78

Table 30 (cont.)

Southeast Asia and East Asia (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
SINGAPORE				
GW 102	Univ. Malaya "A"	978.0815	.06668	+14.82
Pend.	Raffles Mus. "B"	978.0809	.06604	+14.86
WA 2071	Changi RAF "E"	978.0801	.06521	+14.89
WA 2072	Kallang AP "J"	978.0817	.06681	+14.89
WA 2073	Paya Lebar "L"	978.0804	.06561	+14.79
SOLOMON ISLANDS				
WA 3075	Honiara	978.2742	.25984*	+14.36
WA 3073	Munda	978.2541	.23938*	+14.72
TAIWAN				
WA 2007	Taipei "J"	978.9725	.95946	+13.04 site?
THAILAND				
WA 2074	Bangkok "J"	978.3297	.31485	+14.85
VIETNAM				
WA 2078	Hanoi	978.6888	.67409*	+14.71
WA 2079	Hue	978.4367	.42198*	+14.72
WA 2080	Nha-Trang	978.2624	.24769*	+14.71
WA 2081	Saigon "J"	978.2300	.21509	+14.91
	EAST ASIA			
JAPAN				
WA 2032	Itani "J"	979.7171	.70375	+13.35 site ?
WA 2033	Iwakuni	979.6522	.63752*	+14.68
Pend.	Kyoto "A"	979.7216	.70727	+14.33

Table 30 (cont.)

Southeast Asia and East Asia (cont.)

		Woollard and Rose	ICSN 71	Diff. Mgal
WA 2034	Misawa	980.3200	.30534*	+14.66
[illegible]	Tachikawa "S"	979.7830	.77398	+14.02
CW 103	Tokyo "A"	979.8016	.78722	+14.38
WA 2037	Haneda AP "L"	979.7736	.75916	+14.44
CW 103	Sapporo "B"	980.4406	.42735	+13.25
WA 2030	Chitose AP "J"	980.4405	.42734	+13.16
	SOUTH KOREA			
WA 2045	Pusan	979.7780	.77405*	+13.95
WA 2047	Seoul "K"	979.9722	.95847	+13.73
	Seoul "J"	.9722	.95863	+13.57
	OKINAWA			
CW 100	Kadena "A"	979.1265	.11222	+14.28
WA 2057	Kadena MATS "J"	979.1343	.11992	+14.38

tied directly to Tokyo. Since most of the data represented in the lower group were taken with Worden meters at the same time as observations in India, the similarity in slope defined for India and this group is logical and a consequence of no later repeat measurements being taken with better instrumention. The small scatter noted in the concentration of values between 978 and 978.5 gals which accounts for the dominant difference in values of 14.7 mgal in the distribution plot of differences in values is apparently another case of the Woollard and Rose values having been used for control of later observations and for comparisons by other groups at a few key sites agreeing on average to 14.7 mgal as at Port Moresby, Singapore, Manila and Djarkata. In other words, it appears that an areal average value was used in the IGSN 71 adjustments by DMA-AC for many of the sites in the Indonesian, New Guinea and Solomon Is. area.

COMPARISONS IN AUSTRALIA AND NEW ZEALAND

Table 31 presents the differences in the Woollard and Rose (1963) gravimeter values relative to the IGSN 71 values in Australia and New Zealand. The distribution plot of the differences in values is shown in Figure 17E. As seen, a trimodal distribution is indicated with mean values at about 14.25 mgal , 14.55 mgal and 14.9 mgal which suggests the presence of tares. The reality of this is brought out in Figure 19C in which the differences in values are plotted as a function of absolute gravity. However, as seen, the mean difference values differ somewhat from those defined by the distribution plot. The western Australia series (Perth through Wyndham and including Adelaide) has a mean difference of about 15.1 $\pm$0.2 mgal . The series on the East coast north of Brisbane which includes Townsville and Cairns as well as Brisbane appears to have a mean offset of 14.25 $\pm$0.15

Table 31

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values on an Areal Basis in Australia and New Zealand

		Woollard and Rose	IGSN 71	Diff Mgal	
	AUSTRALIA				
Pend.	Adelaide	979.7243	.709 20*	+15.10	
WA 3003	Alice Springs "J"	978.6541	.639 39	+14.71	
GW 85	Brisbane "B"	979.1695	.155 16	+14.34	
GW 85 A	Univ. Seismic Sta. "A"	979.1701	.155 93	+14.17	
WA 3004	Eagle Farm AP "J"	979.1599	.145 57	+14.33	
WA 3067	Archer AP "K"	979.1683	.154 11	+14.19	
GW 87	Cairns "A"	978.5006	.486 24	+14.36	
WA 3009	Carnovan	978.9447	.928 83*	+15.87	site?
WA 3010	Ceduna	979.4534	.438 07*	+15.33	
WA 3059	Daly Waters	978.3892	.374 87	+14.33	
GW 88	Darwin "A"	978.3140	.299 55	+14.45	
WA 3058	RAF Club "B"	978.3164	.301 92	+14.48	
WA 3014	Airport "J"	978.3154	.300 93	+14.47	
WA 3015	Derby	978.5207	.505 69*	+15.01	
WA 3016	Forrest	979.3068	.292 26*	+14.54	
WA 3022	Kalgoorlie	979.2911	.276 95*	+14.15	
WA 3025	Leigh Creek	979.3204	.306 76*	+13.64	site?
WA 3026	Mackay	979.7339	.720 77*	+13.13	site?
WA 3027	Maryborough "A"	979.0219	.007 32	+14.58	
GW 83	Melbourne "A"	979.9797	.965 18	+14.52	
WA 3028	Essendon AP "J"	979.9628	.948 21	+14.59	
	Kallista For. R. "S"	979.9100	.895 38	+14.62	
WA 3031	Mount Isa "J"	978.6190	.604 41	+14.59	
WA 3033	Oodnadatta	979.1006	.086 44*	+14.16	
WA 3034	Onslow	978.7749	.758 81*	+16.09	site?
Pend	Perth Univ "A"	979.3958	.380 86	+14.94	
WA 3035	Airport "K"	979.4011	.386 32	+14.78	
WA 3036	Port Hedland	978.6466	.631 50*	+15.10	
Pend	Rockhampton "A"	978.8707	.856 06	+14.64	
WA 3038	Airport "J"	978.8738	.859 35	+14.45	

Table 31 (cont.)

Australia - New Zealand (cont.)

			IGSN 71	Diff. Mgal
GW 84	Sydney "A"	979.6863	.671 86	+14.44
WA 3042	Kingsford S. "J"	979.6993	.684 80	+14.50
WA 3041	Rose Bay "L"	979.6965	.681 98	+14.52
WA 3042	Tennant Creek	978.5290	.513 69*	+15.31
GW 86	Townsville "B"	978.6247	.610 43	+14.27
WA 3043	Airport "C"	978.6240	.609 66	+14.34
WA 3044	Wyndham	978.4171	.402 18	+14.92
NEW	ZEALAND			
Pend	Auckland Mus. "B"	979.9487	.934 11	+14.59
WA 3047	Whenuapai AP "C"	979.9408	.926 04	+14.76
GW 79	Christchurch "A"	980.5089	.494 29	+14.61
WA 3103	Intl. AP "L"	980.4962	.481 59	+14.61
WA 3049	Harewood AP "K"	980.4962	.481 47	+14.73
GW 89	Duneidin "A"	980.7424	.727 53	+14.87
WA 3051	Taieri AP "C"	980.7366	.721 75	+14.85
WA 3053	Hastings	980.0881	.073 87*	+14.23
GW 81	Wellington "C"	980.2934	.279 09	+14.31
Pend Base	Wellington DSIR "A"	980.2656	.251 00	+14 60
WA 3058	Rongotai AP "K"	980.3064	.292 01	+14.39

mgal , and the balance of the Australian data including New Zealand except for Duneidin which appears to be anomalous has a datum difference of 14.55 mgal ±0.2 mgal. Although there appears to be two superimposed crosscutting alignments of values having a slope similar to that noted in India and Southeast Asia, it is fortuitous in this case as the sites involved were based for the most part on either Melbourne or Sydney.

COMPARISONS ON OCEANIC ISLANDS

The comparative data for Woollard and Rose (1963) gravimeter values relative to IGSN 71 values on oceanic islands are given in Table 32. Although the data are segregated by islands in the Atlantic, Pacific and Indian Oceans, because of the limited number of sites for which there are comparative values and islands representing isolated observations, the combined data are presented in the distribution plot of differences in values (Figure 17F). As seen there is a suggestion of a trimodal distribution with mean values of 14.4 mgal , 14.7 mgal and 15.05 mgal . In presenting the differences as a function of the change in absolute values of gravity, the data were divided into two groups: sites in the north and south Atlantic Ocean and sites in the Pacific and Indian Oceans. In Figure 20A, which presents the data for the islands in the North and South Atlantic areas, the differences in values for continental connections are included. For example, in relating the differences in values for Iceland, Greenland, the Azores and Bermuda, values are also given for Goose Bay, Labrador; St. John, Newfoundland; Caribou, Maine; Washington, D.C. and Charleston, South Carolina. These sites or sites at nearby military bases with good gravity connections were used in making the gravity ties. Similarly Glasgow (Prestwick) was a common

Table 32

Comparison of Woollard and Rose Gravimeter Values and IGSN 71

Values on an Areal Basis on Oceanic Islands

		Woollard and Rose	IGSN 71	Diff. Mgal
	ATLANTIC AREA			
WA 7001	Ascension Is. "J"	978.2943	.27939	+14.91
	AZORES			
WA 7002	Lages, Terceira "J"	980.1762	.16142	+14.67
WA 7003	Santa Maria "L"	980.1167	.10235	+14.35
	BERMUDA			
WA	Kindley "J"	979.8093	.79402	+15.28
WH 1007	Biol. Sta. "P"	979.8232	.80807	+15.13
	GREENLAND			
WA 319	Sondre Stromfjord "J"	982.3843	.37011	+14.19
WA 320	Thule "J"	982.9280	.91375	+14.25
	ICELAND			
WA 7006	Keflavik "K"	982.2744	.25943	+14.97
Natl Base	Reykjavik "A"	982.2800	.26496	+15.04
WA 7007	Reykjavik AP "L"	982.2784	.26333	+15.07
WH 1035	Reykjavik Pier "J"	982.2813	.26634	+14.96
	PACIFIC AREA			
	FIJI			
WA 7010	Nandi "J"	978.5471	.53281	+14.29
WA 7009	Suva	978.6242	.60939*	+14.81
	GUAM			
WA 7011	Agana NAS "J"	978.5240	.50903	+14.97

Table 32 (cont.)

Oceanic Islands (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
HAWAIIAN ISLANDS				
	Honolulu			
GW 55	Bishop Mus. "B"	978.9530	.93835	+14.65
Pend.	Univ. "A"	978.9593	.94490	+14.40
WA 443	Hickam AFB "J"	978.9337	.91914	+14.56
WA 444	Old Int'l AP "S"	978.9325	.91810	+14.40
WA 7015	Midway Is. "J"	979.4993	.48460	+14.70
WH 1041	Pier "P"	979.5077	.49222	+15.48 site?
LINE ISLANDS				
WA 7013	Johnston Is.	978.7198	.70514*	+14.66
NEW CALEDONIA				
WA 7016	Tontouta	978.8590	.84430*	+14.70
PHOENIX ISLANDS				
WA 7017	Canton Is. "J"	978.2932	.27880	+14.40
SAMOA				
WA 7019	Pago Pago "J"	978.6407	.62616	+14.54
SOCIETY ISLANDS				
WA 7020	Bora Bora	978.6703	.65559*	+14.71
WA 7022	Papeete "J"	978.7086	.69353	+15.07
TONGA				
WA 7023	Fua-Amotu AP	978.8722	.85749*	+14.71
WAKE				
WA 7024	Wake Is. "J"	978.8814	.86656	+14.84

Table 32 (cont.)

Oceanic Islands (cont.)

		Woollard and Rose	IGSN 71	Diff. Mgal
WALLIS ISLAND				
WA	Wallis Is.	978.5215	.50679*	+14.71
INDIAN OCEAN AREA				
WA 9004	Cocos (Keeling Is.) "J"	978.4687	.45454	+14.16 site?
WA 9005	Heard Island	981.4778	.46318*	+14.62
WA 9017	Kerguelen Is.	981.0734	.05876*	+14.64
WA 9007	Mauritius Is.	978.8666	.85221	+14.39

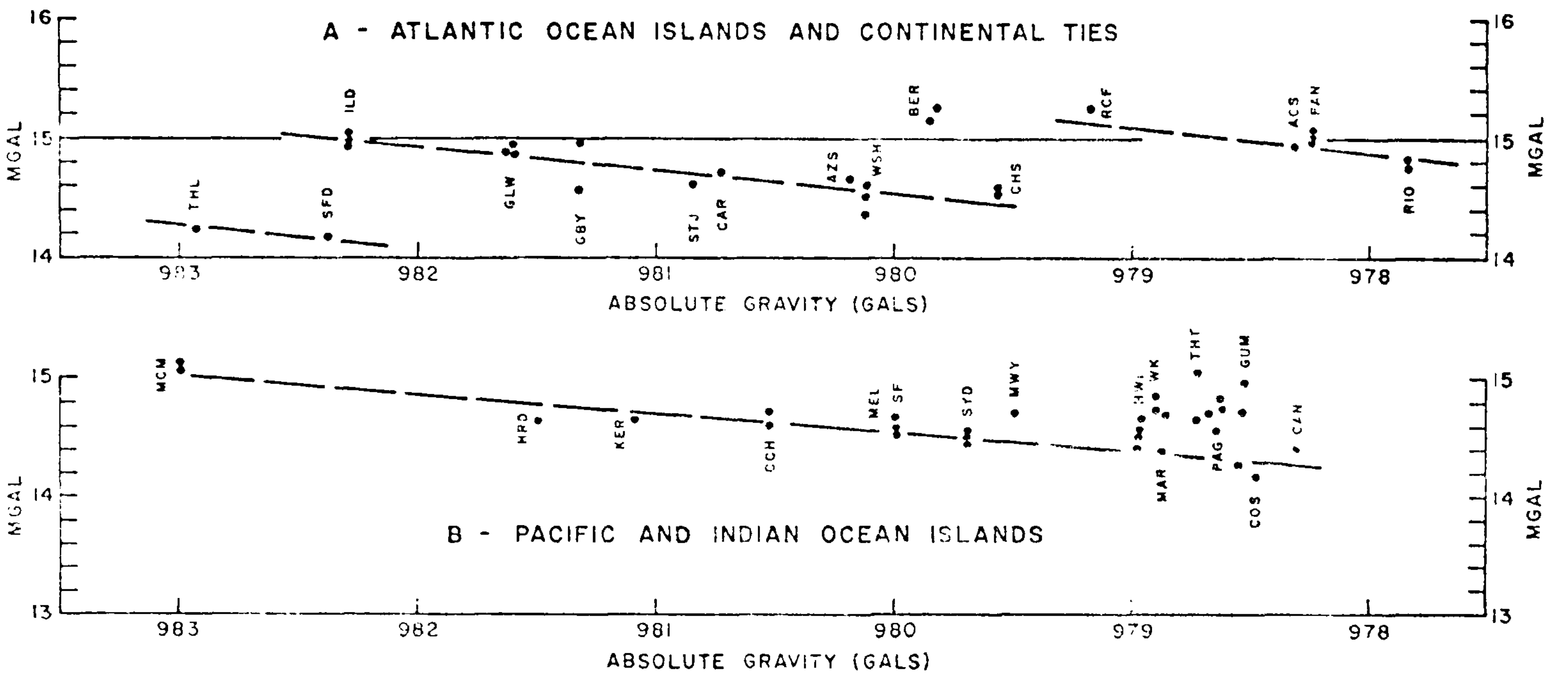


Fig. 20. Differences between Woollard and Rose and IGSN 71 values on oceanic islands A- North and South Atlantic Ocean; B- Pacific and Indian Ocean.

tie point to Europe in making the Woollard and Rose measurements. As seen from Figure 20A, Iceland and the Azores both fall on an alignment with their continental connecting points showing a slope of about 0.2 mgal per 1000 mgal change. However, Bermuda has a positive offset of about 0.7 mgal from this alignment and the sites in Greenland a negative offset of about 0.9 mgal

Similarly, Ascension Island lies on an alignment of differences in values (0.2 mgal per 1000 mgal change) connecting Recife, Panama and Rio de Janeiro which represent continental gravity tie points to this island. That Bermuda also lies on this alignment and contributes to the apparent mean difference values of 15.05 mgal is fortuitous since its data is not tied to the North American mainland.

The data for the Pacific and Indian Oceans are differentiated in Figure 20B in which the values are plotted as a function of absolute gravity. Also included are the differences in values for Honolulu, Hawaii, Sydney, Australia; Christchurch, New Zealand; Melbourne, Australia and San Francisco, California, whose values overlie each other, and McMurdo, Antarctica.

Although there is no discernible systematic departure in the differences in values for the islands in the Pacific Ocean and their relation to mainland North America, there does appear to be a slope relation between the Indian Ocean islands, Australia, New Zealand and Antarctica. This may or may not be fortuitous, but as seen the slope closely approximates that noted in the Atlantic area, Europe and South America.

COMPARISONS IN ANTARCTICA

No comparative data are listed for Antarctica although the

DMA-AC listing of IGSN 71 values includes 15 of the Woollard and Rose sites in this area. The reason for not using these data is that a constant difference in values of 14.6 mgal in indicated for all sites except McMurdo which is the only Antarctic site that appears to have been adequately evaluated. Morelli et al. (1974) whose listing of IGSN 71 values only includes 3 sites which can be definitely identified as being the same as Woollard and Rose sites, indicate differences ranging from 14.47 to 15.12 mgal which is more in line with the differences in values to be expected. The differences for these sites based primarily on numerous connections to a site not listed by Woollard and Rose (the Biology Laboratory at McMurdo) are as given below in Table 33.

TABLE 33

COMPARISON OF WOOLLARD AND ROSE VALUES IN ANTARCTICA

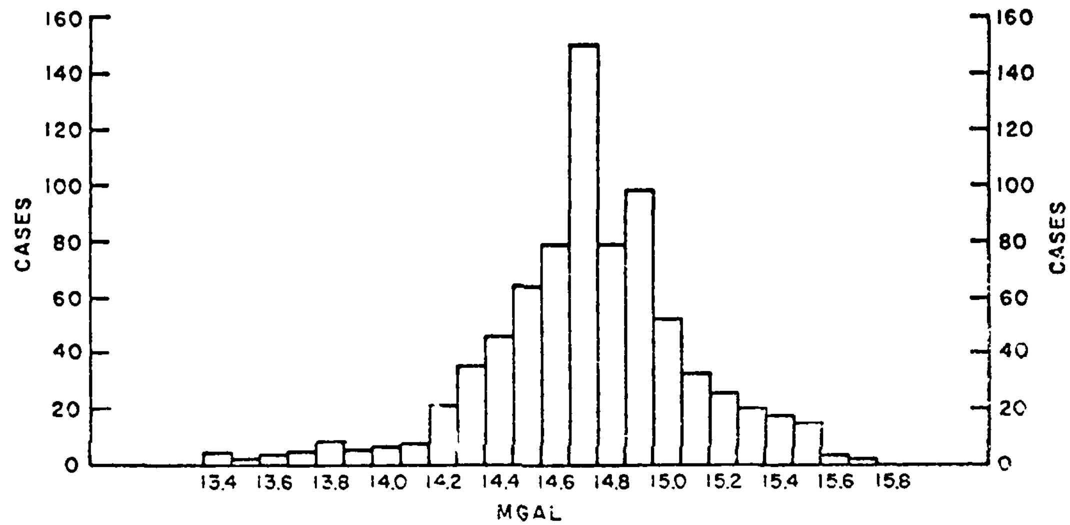
	Woollard and Rose	IGSN 71	DIFF
WA 9006 Hallet 'J'	982.7049	.68986	+15.04
GW 82 McMurdo 'A'	982.9919	.97683	+15.07
WA 9013 Scott Base 'L'	982.9883	.97318	+15.12
WA 9011 Helicopter Port 'N'	982.9911	.97662	+14.48 site?
WA 9010 Air Ops Bldg 'D'	982.9890	.97345	+15.55 site?

The only reason for questioning the last two sites is that there were repeated reoccupations of the pendulum base which would not allow a discrepancy on the order of 0.5 mgal.

CONCLUSIONS ON THE WOOLLARD AND ROSE GRAVIMETER VALUES RELATIVE TO THE IGSN 71 VALUES

As brought out on a continent by continent and area by area basis, the Woollard and Rose values, whereas subject to some internal problems as regards consistency in calibration standard as well as the effect of tares, have differences relative to the IGSN 71 values that are confined within bounds of ± 0.5 mgal from a world wide mean difference value of approximately 14.7 mgal for 88 percent of the data that can be compared (686 of the 776 comparisons). This is brought out in Figure 21 showing the differences in values for all areas. The only block of data on a continental basis that shows any significant departure from the world mean is South America where a significant difference in calibration standard of 0.2 mgal per 1000 mgals change is also indicated. Here the mean difference value as brought out in Figure 22C is 14.9 mgal. The data for North America (Figure 22A) indicate a mean difference value of 14.65 mgal, and that for the rest of the world excluding South America (Figure 22B), although somewhat skewed, have a well defined mean difference value of 14.7 mgal. If the ± 0.3 mgal general reliability estimate for the Woollard and Rose values is applied relative to the mean difference value of 14.7 mgal relative to the IGSN 71 values, it is found that 570 of the 776 comparisons (74 percent) would be included within these bounds and define an average mean difference value of 14.72 mgal.

The apparent overall consistency of the Woollard and Rose (1963) gravimeter values in defining no significant difference in gravity standard from that incorporated in the IGSN 71 values except in South America, India and locally elsewhere is in large measure fortuitous. It is a consequence of compensating tares as brought out for Europe and East Asia where consideration of all the data rather than just the gravity standardization bases indicated that there are differences in calibration standard involved which tend to



DIFFERENCES WOOLLARD AND ROSE VALUES
RELATIVE TO IGSN 71 VALUES WORLDWIDE

Fig. 21. Distribution plot of difference in Woollard and Rose values and IGSN 71 values on a worldwide basis.

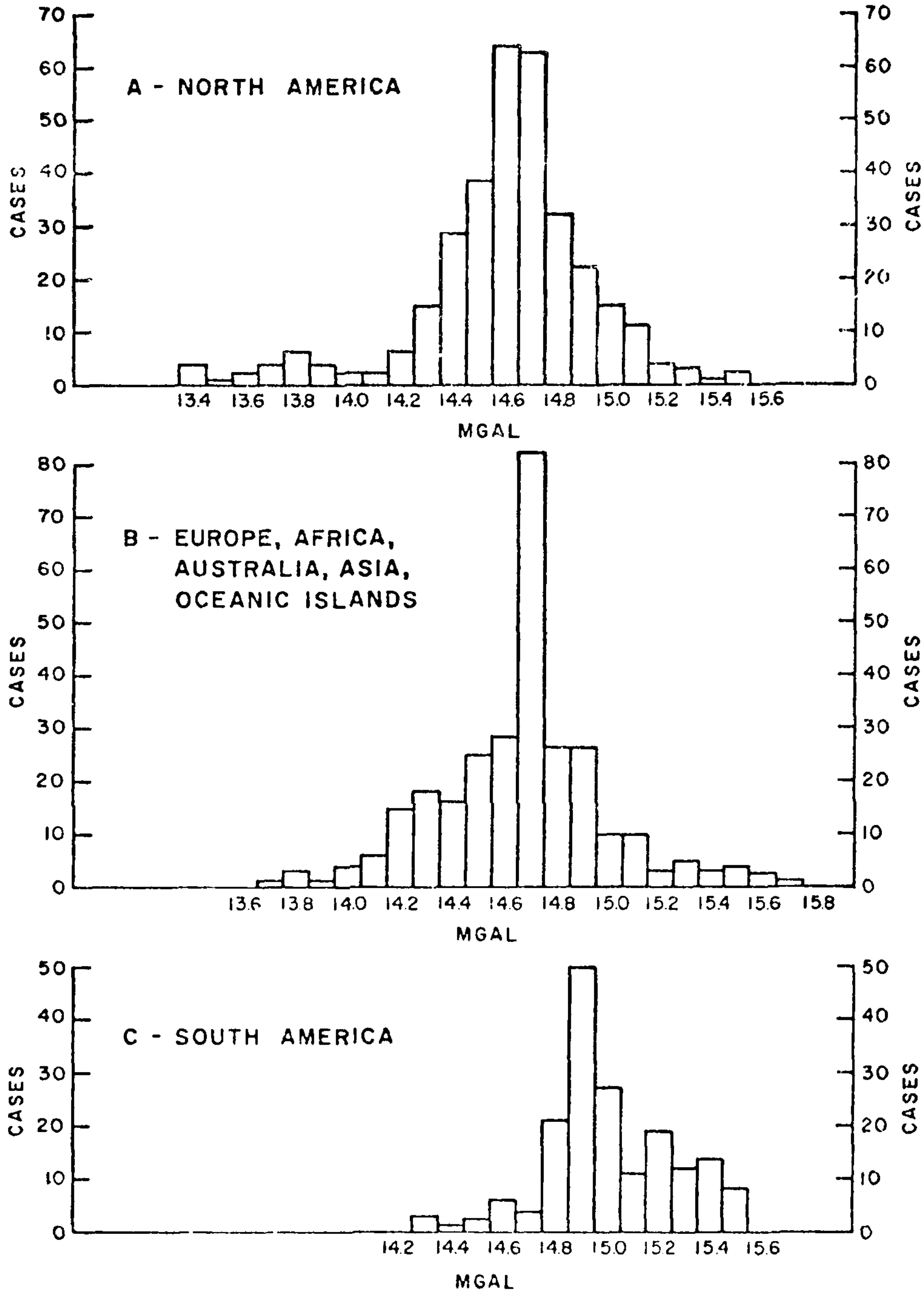


Fig. 22. Distribution plot of difference in Woollard and Rose values and IGSN 71 values in terms of the three principal grouping of differences in values A- North America; B- Europe, Africa, Australia, Asia and Oceanic Islands; C- South America.

be masked by datum offsets related to tares. This is particularly true for Woollard and Rose values in Europe, and where it occurs there is an apparent high degree of uncertainty in the gravity standardization base values even though no difference in gravity standard is indicated on an overall basis.

That a major part of the problems brought out in the Woollard and Rose (1963) values is related to the fact that the instruments used were in large part prototypes with inherent problems that were not recognized until much later is quite evident. Much of the work was also done with single instruments and with no comparative values from other sources. Outside of local surveys there were few comparative data having relative reliability for international gravity connections that were better than 1.0 to 5.0 mgal . The data reflect these problems inherent in the initial stages of high range gravimeter development and measurements. It is also clear that the 1962 adjustments made in trying to fit data taken over nearly a 15-year period on a world-wide basis with a number of instruments having various standards of calibration as well as other problems into a cohesive body of values on a single gravity standard was not everywhere completely successful. Vestigal signatures of early problems are evident in the data for several areas which were occupied in the early 1950's and for which there had been no later reoccupations of the same sites. However, even with the best of data and the use of computers there can be problems in adjusting widely disbursed data to a common datum and standard. This is well illustrated in Figure 23 which shows plots of the differences between the IGSN 71 values as adjusted by DMA-AC and as adjusted by Morelli et al. (1974) for the same sites on a world-wide basis using the same data. Although the differences are small and in general

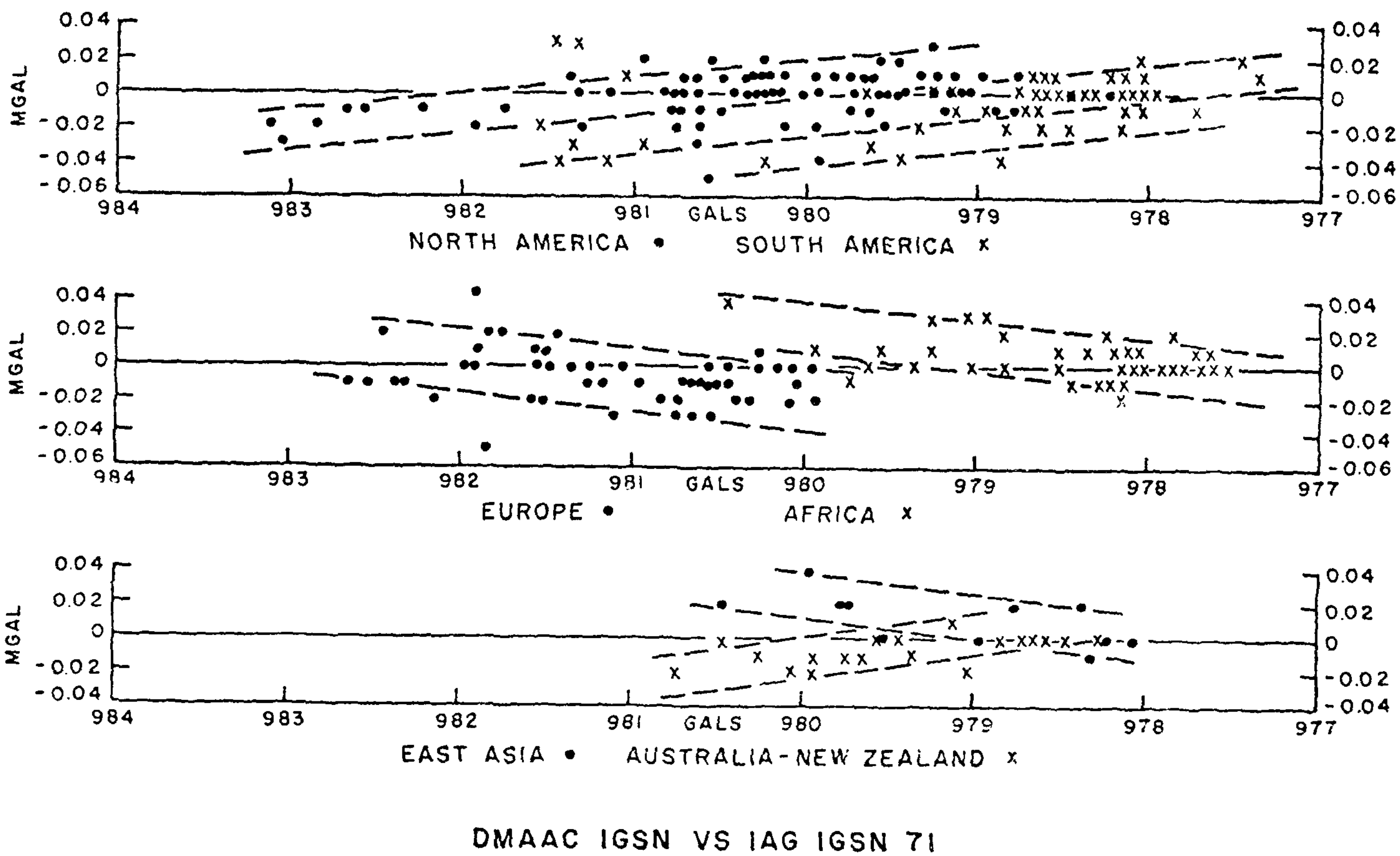


Fig. 23. *Difference in IGSN 71 values as determined by DMAAC and Morelli, et al. (1974) as a function of absolute gravity.*

do not exceed ± 0.04 mgal, it is clear that there are datum offsets (the equivalent of tares) in the adjustments in going from one continent to another, and that the gravity standard defined not only differs but actually changes sign in going from one continental area to another. The same types of problems brought out in the Woollard and Rose (1963) values relative to the IGSN 71 values are thus present in the IGSN 71 adjustments and contribute somewhat to the scatter in the Woollard and Rose comparisons as do secular changes in gravity whose importance is only now beginning to be recognized. The significant thing is that despite points of weakness in the IGSN 71 values they still represent the best series of global gravity values now extant, and therefore, should be adopted until better values become available. Also as brought out earlier, the degree of improvement that might be anticipated will be small in both terms of the absolute gravity standard defined and the absolute reliability of individual values for datum control.

THE CONVERSION OF GRAVITY ANOMALY VALUES BASED ON THE 1930 INTERNATIONAL GRAVITY FORMULA AND THE OLD POTSDAM DATUM VALUE TO GEODETIC REFERENCE SYSTEM 67 AND THE INTERNATIONAL GRAVITY STANDARDIZATION NET 71 ANOMALY VALUES

Because there are only gravity anomaly maps now available for many areas, or incomplete data which preclude the recomputation of anomaly values on the new GRS 67 gravity reference system and the IGSN 71 gravity datum and standard, it is desirable to be able to convert gravity anomaly values determined on the old system to the new system. This can be done quite easily if there are gravity control data (either IGSN 71 values or Woollard and Rose values) available for an area, and even if the original observations were on a floating datum, as for example, based on an arbitrary value for the lower step of the Methodist Church in Ebeneezer, Georgia rather than a pendulum or other site on the Potsdam system. If the data were based on some defined gravity reference station, the situation is simpler in that the difference in anomaly value for that site under the new system relative to the old gives a correction constant for the base which is only modified by the difference in the theoretical latitude effect under the old and new system in moving North or South from the latitude of the base. As Table 1 gives the difference in theoretical sea level gravity values for any latitude under the old 1930 International Gravity Formula and that for the new Geodetic Reference System 1967, this value plus the base datum correction to the IGSN 71 value is all that is needed to go directly from the old anomaly value to what it would be under the new system. This, of course, assumes there is no significant difference in gravity standard. If there is a difference in gravity standard involved, and this can only be detected where there are two or more control sites in a survey area for which there are IGSN 71 values and also a large change in gravity is involved, this correction would in general be a function of the difference in Bouguer anomaly values as originally computed and as determined at the control sites. However, to illustrate the simplest case assume a shipboard gravity survey based out of Honolulu where the average difference in observed gravity values as defined by Woollard and Rose (1963) relative to IGSN 71 values at the Bishop Museum pendulum gravity base and five excenter sites is +14.5 mgal . For an offshore site at 22° North latitude the free air anomaly as defined in 1965 was +156.92 mgal . To convert to the new system this value has to be corrected by +14.5 mgal to get the value on the IGSN 71 datum and by 15.4 mgal for the difference in theoretical sea level gravity under the GRS 67 formula and the 1930 International gravity formula as defined in Table 1 for Latitude 22°. Although the sign of the correction for the latitude effect is minus it is applied as a positive correction since

$$FA = G_0 - \gamma_0$$

where FA = free air anomaly

G_0 = observed gravity

γ_0 = theoretical gravity at sea level

Under the new system G_0 = old G_0 - 14.5 mgal

γ_0 = old γ_0 - 15.4 mgal

$$\text{new FA} = (\text{old } G_0 - 14.5) - (\text{old } \gamma_0 - 15.4)$$

or

$$\text{new FA} = \text{old FA} - 14.5 + 15.4$$

$$= \text{old FA} + 0.9 \text{ mgal}$$

$$= +156.92 + 0.9 = +157.82 \text{ mgal}$$

That the above conversion scheme applies equally well to Bouguer anomalies and free air anomalies not at sea level is clear since all the other correction terms involved in defining anomaly values are only dependent on the free air gravity gradient, elevation or depth of water and the density terms used which are not changed.

As the dominant average difference in datum defined by the Woollard and Rose (1963) gravimeter values relative to the IGSN 71 values on a world-wide basis is 14.7 mgal , Table 34 has been prepared to give the net anomaly corrections for this datum difference (-14.7 mgal) and the difference in theoretical gravity under the old and new gravity formulas for each 1° of latitude between the equator and the poles. As seen from Figure 24 the correction has the same form as the difference between the old and new theoretical gravity values at sea level, and varies from +2.45 mgal at the equator to -11.13 mgal at the poles. As the theoretical latitude correction term is fixed and always positive in sign in the anomaly correction, and the datum correction term is always negative in sign, any datum correction less than the 14.7 mgal incorporated in Table 34 will represent a positive incremental correction to the values shown. For example if the local datum difference relative to the IGSN 71 values is 14.5 mgal rather than 14.7 mgal , the values given in Table 34 for the equator would be increased from +2.45 mgal to +2.65 mgal and at the poles would be decreased from -11.13 mgal to -10.93 mgal . If the datum difference relative to the IGSN values is greater than 14.7 mgal the incremental correction would similiarly decrease the values shown at the equator and increase the values shown for the poles.

If only a Bouguer anomaly map exists for an area and no station sites can be identified or none are shown but it is known what base value

Table 34

Conversion Table for Anomaly Values Pre 1971 to values based on GRS 1967 Theoretical Gravity Formula with f=1/298.25 and IGSN 71 values. Datum correction (-14.7 mgal) corresponds to that for average of Woollard and Rose (1963) values on a worldwide basis.

Lat	mgal corr.	Lat	mgal corr.	Lat	mgal corr.	Lat	mgal corr.	Lat	mgal corr.
0°	+2.45	18°	+1.15	36°	-2.26	54°	-6.46	72°	- 9.83
1°	+2.45	19°	+1.01	37°	-2.58	55°	-6.67	73°	- 9.97
2°	+2.44	20°	+0.86	38°	-2.71	56°	-6.89	74°	-10.10
3°	+2.41	21°	+0.70	39°	-2.94	57°	-7.12	75°	-10.22
4°	+2.39	22°	+0.54	40°	-3.18	58°	-7.33	76°	-10.34
5°	+2.35	23°	+0.37	41°	-3.41	59°	-7.54	77°	-10.44
6°	+2.31	24°	+0.20	42°	-3.65	60°	-7.75	78°	-10.55
7°	+2.25	25°	+0.01	43°	-3.88	61°	-7.94	79°	-10.63
8°	+2.19	26°	-0.17	44°	-4.12	62°	-8.15	80°	-10.72
9°	+2.12	27°	-0.36	45°	-4.36	63°	-8.34	81°	-10.80
10°	+2.04	28°	-0.56	46°	-4.59	64°	-8.53	82°	-10.87
11°	+1.96	29°	-0.75	47°	-4.83	65°	-8.72	83°	-10.93
12°	+1.87	30°	-0.96	48°	-5.07	66°	-8.89	84°	-10.98
13°	+1.76	31°	-1.16	49°	-5.30	67°	-9.06	85°	-11.02
14°	+1.66	32°	-1.38	50°	-5.53	68°	-9.23	86°	-11.06
15°	+1.54	33°	-1.59	51°	-5.77	69°	-9.39	87°	-11.09
16°	+1.42	34°	-1.81	52°	-6.00	70°	-9.55	88°	-11.11
17°	+1.29	35°	-2.03	53°	-6.22	71°	-9.69	89°	-11.13
18°	+1.15	36°	-2.26	54°	-6.46	72°	-9.83	90°	-11.13

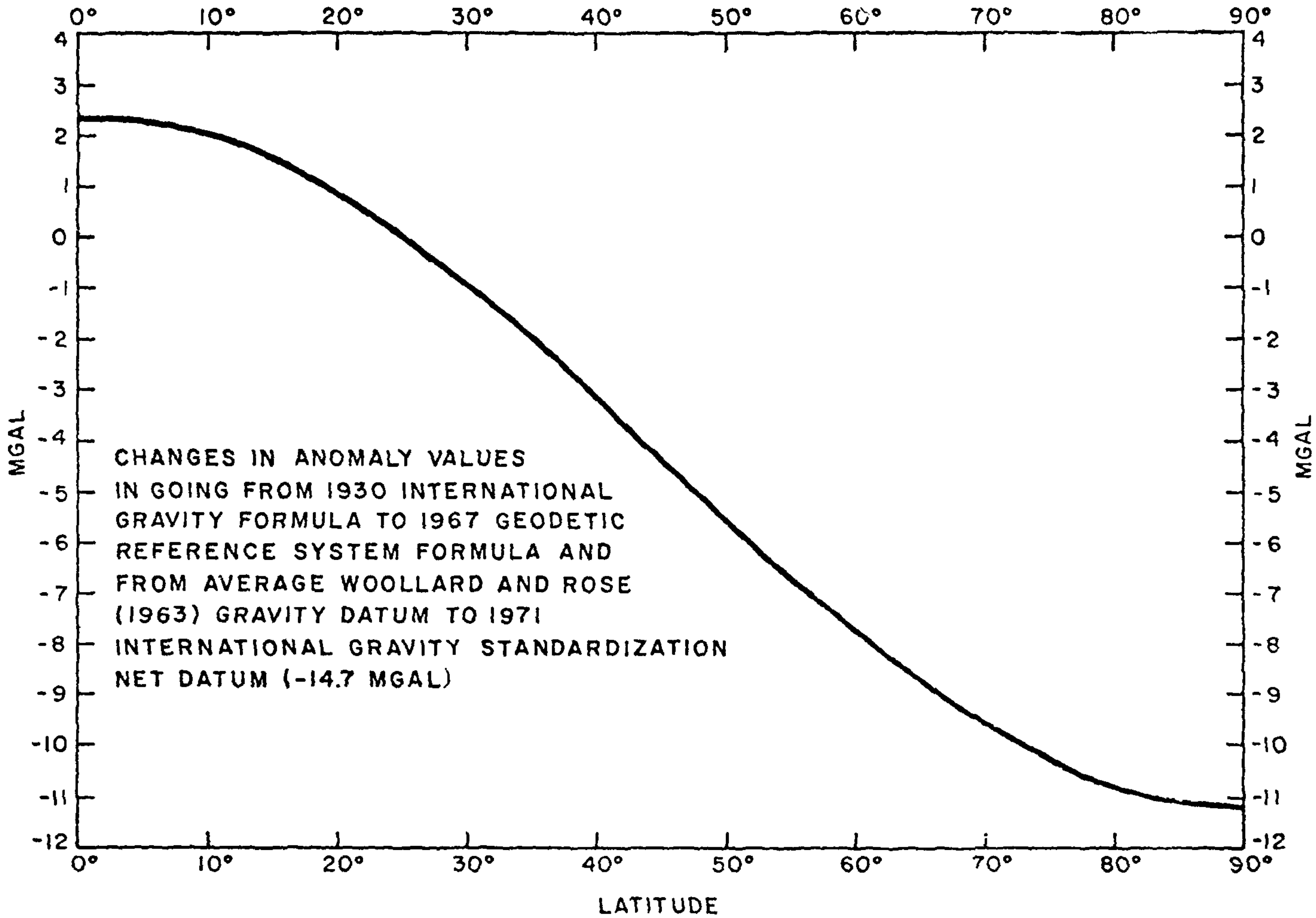


Fig. 24 Correction in mgal for each 1° of latitude in converting anomaly values based on the 1930 International Gravity formula and old Potsdam datum to GRS 67 gravity Formula and IGSN 71 gravity values assuming -14.7 mgal average datum correction for Woollard and Rose (1963) International Gravity Measurements.

was used and its relation to the IGSN 71 datum can be established to at least a first approximation, a transparent overlay of parallels of latitude tagged as to the corrections applicable will define the correction at each contour crossing of a given parallel. If this is done with a digitizer, a new anomaly map can be prepared on the IGSN 71 standard from the resulting point values with a minimum of labor.

If the base datum is not known but there is a subsequent control site in the area for which the IGSN 71 value is known, computation of the anomaly value for that site will give a base value for similarly correcting the anomaly values to the IGSN 71 gravity datum and GRS 67 reference ellipsoid.

SUMMARY

The important points brought out in this paper are as follows:

1 - The change in gravity anomaly values occasioned by the adoption of Geodetic Reference System 1967, the change of -14.0 mgal in the Potsdam absolute gravity datum, and the gravity standard incorporated in the IGSN 71 gravity values based on modern absolute determinations of gravity is significant; on an overall basis this amounts to some 13 mgal between the equator and the poles.

2 - On the basis of relative pendulum gravity connections between the sites for modern absolute gravity determinations (Washington, Teddington and Paris) and Potsdam, the Potsdam correction of -14.0 mgal is essentially correct. On the basis of these connections and the differences in absolute values relative to the old reference value for Potsdam on the reference pier (981.274 15 gals) the correction defined is -13.970 ± 0.16 mgal.

3 - The IGSN 71 gravity standard does not conform exactly to that defined by the modern absolute gravity determinations, and appears to be about 0.03 mgal per 1000 mgal low on an overall basis.

4 - The IGSN 71 adjusted gravity values incorporate some errors. One of the most glaring, amounting to about 0.1 mgal, appears to be in the value for the absolute gravity site at Teddington, England. On the basis of both absolute gravity values at Washington, Paris and Teddington as well as relative pendulum gravity connections between absolute sites and their difference from the IGSN 71 values for these sites, the IGSN 71 values for Teddington is 0.135 mgal low relative to Washington and 0.084 mgal low relative to Paris.

5 - The Woollard and Rose (1963) gravimeter values representing pioneer measurements made for the most part with prototype early model high range gravimeters during the period 1949-1962 and having an estimated general reliability of ± 0.3 mgal, on the basis of 776 comparisons with IGSN 71 values have a mean average datum offset of 14.7 mgal from that of the IGSN 71 values. Although the spread in the difference in values is large (13.4 to 15.7 mgal) 74 percent of the values evaluated (776) would fall within the bounds of the ± 0.3 mgal estimated reliability relative to the mean average difference value of 14.7 mgal, and 88 percent of the values would fall within the bounds of ± 0.5 mgal from the mean average value.

6 - In terms of the gravity standard defined by the Woollard and Rose (1963) gravimeter values relative to that incorporated in the IGSN 71 values, comparative values at the pendulum sites along each of the principal North-South gravity standardization range indicate no discernible difference in gravity standard except for the Andean series of measurements from

Panama to Punta Arenas, Chile. For this series the Woollard and Rose values show a systematic departure in values of 0.2 mgal per 1000 mgal change in gravity. The relation to the IGSN 71 values for this series of values is defined by the equation

$$X = 15 + [\ 0.2\ (\text{Woollard and Rose value} - 978.5)\ ]$$

When all the Woollard and Rose data for each area are examined it is found that a similar slope of +0.2 mgal per 1000 mgal change characterizes the data for Europe and for island connections from continental areas in both the Atlantic and Indian Oceans. This slope is not obvious in the more limited European gravity standardiztion range data as there are two parallel groupings of values offset from each other by 0.4 mgal which effectively masks the slope present and defines a constant datum difference on an overall basis with a relatively large ($\pm$0.25 mgal) degree of uncertainty in the individual values relative to the mean.

One other area where a slope is brought out when all the data are considered is India. In this case the slope is about -0.8 mgal per 1000 mgal change. This appears to be a vestigal remnant from early uncertainties in gravimeter calibration that was not removed in the Woollard and Rose adjustment of their data. Evidence for this same slope was also found in the early data for Argentina, Alaska, Mexico and Southeast Asia.

Tares (internal offsets in datum) were also brought out in the Woollard and Rose data for Africa, Australia and in the East Pacific region as well as in the eastern half of South America.

In view of these abberations the overall degree of agreement of the Woollard and Rose values with the IGSN 71 values is surprisingly good.

7 - That the IGSN 71 adjustments of values also incorporate tares

and differences in gravity standard but to a lesser degree than in the Woollard and Rose values as regards the magnitude of the tares and slope values is brought out by a comparison of the IGSN 71 values as defined by Morelli et al. (1974) and the Defense Mapping Agency-Aerospace Center (unpublished). These comparisons indicate datum offsets between each continent and slopes that change in sign.

8 - Although there is clearly a need to upgrade the IGSN 71 values and resolve problems brought out under paragraph 3, 4 and 7 above, the IGSN 71 values do appear in general to have an absolute reliability of 0.1 mgal on a global basis. They thus represent a significant advance in standardizing gravity throughout the world, and as brought out by the Woollard and Rose (1963) comparisons, are clearly superior in many respects to this earlier attempt to do so.

9 - By using the differences in theoretical gravity at sea level as defined by the old (1930) International Gravity Formula and that as defined by the new formula based on Geodetic Reference System 1967 with the datum difference relative to the IGSN 71 values and any applicable difference in gravity standard relative to that incorporated in the IGSN 71 values, it is possible to go from old (pre 1971) gravity anomaly values to new (post 1971) gravity anomaly values without having to completely recompute the anomaly values. This is of particular value in converting old gravity anomaly maps to the new standard where the original data have been lost totally or in part.

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